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STUDY OF THREE START HELICAL ABRASIVE FLOW MACHINE FOR DUCTILE MATERIALS

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Submitted By

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(Session 2011-13)

CERTIFICATE

Date _________

This is to certify that report entitled **"STUDY OF THREE START HELICAL ABRASIVE FLOW MACHINING"** by **Mr. RAHUL KUMAR,** is the requirement of the partial fulfillment for the award of Degree of **Master of Technology (M. Tech.)** in **Production Engineering** at **Delhi Technological University**. This work was completed under our supervision and guidance. He has completed his work with utmost sincerity and diligence. The work embodied in this project has not been submitted for the award of any other degree to the best of my knowledge.

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Rahul Kumar

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ABSTRACT

Abrasive flow machining (AFM) is a process that finishes complex internal and external geometries with the help of viscoelastic abrasive medium, while keeping in mind its low finish and material removal rates (MRR). Researchers have often strived to improve finishing rate and MRR. As an attempt to overcome the said limitations, this project report discusses Helical abrasive flow finishing (H-AFM) process where a three star helical drill bit is used coaxially with in the hollow cylindrical workpiece using three piece nylon fixture . The developed Helical-Abrasive flow machining process employs a standard helical drill-bit, which forces the abrasives laden media to follow a helical path within the finishing zone Curvature in the path of abrasives laden media, leads to development of centrifugal forces in the media in addition to a combination of different media flows (flow along the flute, axial flow, and scooping flow, and remixing of medium at exit from the finishing zone.

For the present problem a three-start helical profile have been developed for the conduct of experiments and to study the effect of these on various response parameters. For the experimentation on the Helical-AFM setup, helical profile rod needs to be retained along the axis of the hollow cylindrical work-piece. The experimental design was according to an L9 orthogonal array based on the Taguchi method to study the effects of the helix rod and other main AFM process parameters. The main parameters are [type of materials Brass, Gun metal, and Mild steel] (M),Number of cycles (N), extrusion pressure (P), have been selected at three levels considering no-interaction among them.

L9 orthogonal array based on the taguchi method has been used to study the effect of the helical drill bit and other main AFM process parameters. The main parameters are shape of the Type of material(M), Extrusion pressure (P), Number of cycles (N), has been selected at three levels considering no interaction among them.

A maximum improvement of 51.42% has been observed in the Surface finish. With the initial roughness 3.5 microns, an improvement to 1.70 microns has been observed on the inner cylindrical surface of the gunmetal work pieces.

ORGANISATIONS OF THESIS

Chapter 1 contains the introduction of non conventional manufacturing process along with the detail description of AFM Technology and Helical-AFM.

Chapter 2 Contains with literature review along with status of current research in this field, and objectives of proposed research work to be carried out.

Chapter 3 contains the schematic of Drill bit assisted AFM process and development of Helical-AFM.

Chapter 4 contains TAGUCHI'S EXPERIMENTAL design and analysis.

Chapter 5 contains selection of process parameters and their range and response characteristics.

Chapter 6 Contains analysis and result discussion.

Chapter 7 contains conclusion and scope for future work.

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ACRONYMS

AFM	Abrasive flow machining
AJM	Abrasive jet machining
ANOVA	Analysis of variance
CBN	Cubic boron nitride
DOF	Degree of freedom
CFAAFM	Centrifugal force assisted abrasive flow machining
CFG	Centrifugal
MR	Material removal
MRR	Material removal rate
MSD	Mean square deviation
NCM	Non-conventional machining
OA	Orthogonal Array
PGR	Polymer gel ratio
R	Sample size of confirmation experiment
ΔR_a	Percentage improvement in surface roughness
WZM	Water jet machining
USM	Ultrasonic machining

CHAPTER 1

INTRODUCTION

Abrasive Flow Machine (AFM) operates by flowing an abrasive laden viscoelastic compound through a restrictive passage formed by a work part/tooling combination.. Abrasive Flow Machine (AFM) is a nontraditional machining process that is used to deburr, polish, radius, and remove recast layers of critical components in aerospace, automotive, electronic and die-making industries.

This technique uses a liquid polymer containing abrasive particles as grinding media. Hydraulic pressure systems help in extruding the abrasives laden media through a controlled passage formed by the work-piece and necessary tooling. During the extrusion of the media, the abrasion of the work-piece material takes place and it results in a finished product.

In the recent times, some of the advanced abrasive flow machining processes using the additional energy or modified tooling to increase the machining forces and thus the faster material removal and/or more finishing have been developed as discussed further. Singh and Shan [2-3] and Singh et al. [4] employed a magnetic field around the work-piece in abrasive flow machining process to improve the machining performance and termed the modified abrasive flow machining process as Magnetic Assisted Abrasive Flow Machining (MAAFM). Jha and Jain developed a new precision finishing process for complex internal geometries using smart magneto-rheological polishing fluid and termed it as Magneto-rheological abrasive flow finishing (MRAFF) process [5]. Walia et al. rotated the medium by using different shaped rods to improve finishing ability, to increase number of dynamic active grains and to achieve better finish in cylindrical part and termed it as Centrifugal force assisted abrasive flow machining (CFAAFM) process[6-8]. Yan et al. [9] and Chan et al. [10] used spiral-fluted screw in the medium flowing path to improve surface quality. Sankar et al. employed a drill-bit to rotate the medium along its axis to achieve higher rates of finishing and termed it as drill bit-guided abrasive flow finishing (DBG-AFF) process [11]. Sankar et al. also provided rotary motion to the work-piece (termed R-AFF: rotational abrasive flow finishing) and found more material removal and better surface finish [12]. Taguchi Method helps in developing robust products and manufacturing systems that are insensitive to daily and seasonal variations of environment, machining wear etc. [13]. Taguchi method is widely used in engineering analysis to design high quality systems. Special orthogonal arrays in the

Taguchi Method help in investigating the effects of the entire machining parameters through small number of experiments. The orthogonal array forces all experimenters to design almost identical experiments [14-15]. In the present investigation, a coaxially held drill-bit has been employed to enhance the material removal rate of the AFM process without any additional power drive.

This process with simple modification has been named as helical-abrasive flow machining (HLX-AFM) process because of the use of a helical profile along the axis [16]. Further the developed HLX-AFM setup has been optimized for the various process parameters using the Taguchi Method towards the development of robust system. Like the general AFM, this process is suitable for the fine polishing of roughly machined work-pieces, improving the flow characteristics of fluid carrying channels, removing the burrs and recast layers, radiusing the edges of different work-pieces/components, but because of the employment of drill-bit the applications of HLX- AFM are limited to the finishing of cylindrical shaped geometrical surfaces only e.g. cylinders and sleeves or some part of cylindrical surfaces using suitably modified toolings. Unlike AFM process, even large surface irregularities, such as deep scratches or bumps, can be removed by the developed HLX-AFM process resulting in the corrections of macro geometrical errors like out-of-roundness, form and taper. This process may find applications in medical technology, hydraulic and pneumatic components, automobile, space and aeronautics industry.

1. NON-CONVENTIONAL MACHINING PROCESSES

Non- Conventional machining refers to a group a processes which removes excess material by various techniques involving mechanical, thermal, electrical or chemical energy. These processes do not use a sharp cutting tool in the conventional sense The need to machine newly developed materials with special properties (high strength, high hardness, high toughness), unusual and/or complex geometries and to avoid surface damage.

1.1 Classification of nonconventional machining processes by principle form of energy

(i) Mechanical

Mechanical energy in some form different from the action of a conventional cutting tool; erosion of the workpiece material is typical

(ii)Electrical

Electrochemical energy to remove material

(iii)Thermal

Thermal energy generally applied to a small portion of the work surface, causing removal by fusion and/or vaporization, thermal energy is generated by conversion of electrical energy

(iv)Chemical

Most materials are susceptible to chemical attack by certain acids or other etchants, chemicals selectively remove material from portions of the workpiece, while other portions of the surface are protected

Table 1.1 Available conventional material removal processes by principle form of energy

Mechanical	**Electrical**	**Thermal**	**Chemical**
Abrasive flow machining (AFM)	Electrochemical deburring (ECD)	Electron beam machining (EBM)	Chemical machining (CHM)
Abrasive jet machining (AJM)	Electrochemical discharge grinding (ECDG)	Electrical discharge grinding (EDG)	Electro polish (ELP)
Hydrodynamic machining (HDM)	Electrochemical grinding (ECG)	Electrical discharge machining (EDM)	Photochemical machining (PCM)
Low stress grinding (LSG)	Electrochemical honing (ECH)	Electrical discharge sawing (EDS)	Thermochemical machining (TCM)
Rotary ultrasonic machining (RUM)	Electrochemical machining (ECM)	Electrical discharge wire cutting (EDWC)	
Thermally assisted machining (TAM)	Electrochemical polishing (ECP)	Laser beam machining (LBM)	
Total form machining (TFM)	Electrochemical sharpening (ECS)	Laser beam torch Chemical (LBT)	
Ultrasonic machining (USM)	Electrochemical turning (ECT)	Laser beam torch Chemical (LBT)	
Water jet machining (WJM)	Electro-stream (ES)		

So above are some nonconventional machining processes which are recently used for solving different purposes of the manufacturing industry.

1.2 AFM TECHNOLOGY

In AFM, a medium containing abrasive in polymer laden is extruding through component. A pre-requisite for creating a restrictive passage for directing the medium to the work-piece's desired locations is achieved with a fixture. Random cutting edges with different geometry, wide variation in orientation and large in number are basically used for effective removal of material in this process. The work-piece placed in holding fixtures is hydraulically clamped between two vertically opposed cylinder carrying media used for machining. The media get extruded through work-piece into the upper cylinder by piston pressure of bottom cylinder, in forward direction. Consequently, the medium abrade the work-piece in the work holder. The procedure is reversed. Complete process cycle is the combination of forward stroke and backward stroke.

1.3 CLASSIFICATION OF ABRASIVE FLOW MACHINE

AFM machines are classified into two categories according to the direction of flow of abrasive media i.e. one way AFM and two way AFM.

1.3.1One way AFM process

In one way AFM process is provided with a hydraulically actuated reciprocating piston and an extrusion medium chamber adapted to receive and extrude medium unidirectional across the internal surface of the work piece having internal passage formed therein the media is extruded inside the work piece only in one direction. For this purpose the setup has a. Piston direct the media through the internal passage of the work piece while a medium collector collects the media as it is extruded out through the work piece. The extrusion media chamber is provided with an access port to periodically receive medium from the collector into extrusion medium chamber. The hydraulically actuated piston intermittently withdraws from its extruding position to open the extrusion medium chamber access port to collect the medium in the extrusion medium chamber. When the extrusion medium chamber is charged with the working medium, the operation is resumed.

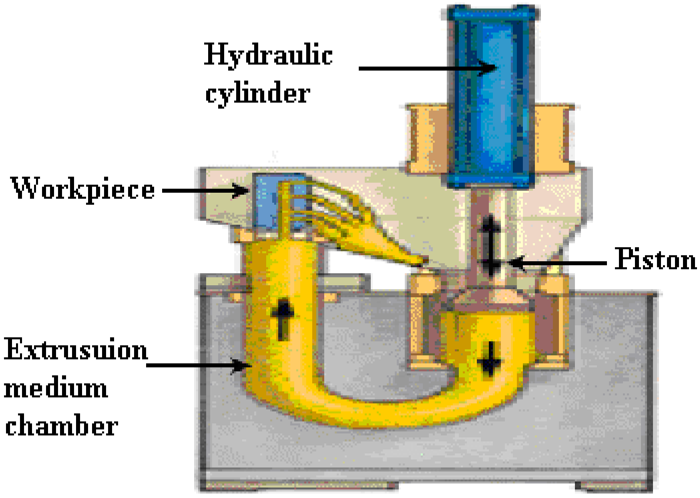


Figure 1.3(a) one –way AFM [17]

1.3.2. Two-way AFM process

In **Two-way AFM process** prior to machining, liquid abrasive will be put into the lower medium cylinder, the designed fixture which clamping the workpiece will be fixed between two cylinders. The upper medium, lower medium cylinder and fixture will form a confined space. After heat the whole system to working temperature, by forcing the lower piston (usually by hydraulic), the liquid abrasive will be pressed into the channel formed by clamp and workpiece, then flow into the upper medium cylinder. After the stroke of lower piston finished, the upper piston will force the liquid abrasive back into lower cylinder , an operating cycle will be finished.

In (Fig.1.2). the medium is extruded back and forth between the chambers for the desired fixed number of cycles. Counter bores, recessed areas and even blind cavities can be finished by using restrictors or mandrels to direct the medium flow along the surfaces to be finished.

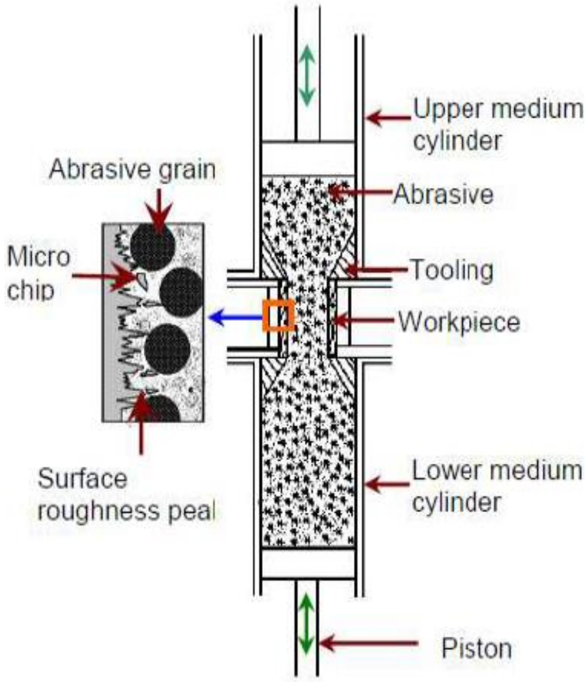


Figure 1.3(b) Two way AFM [17]

1.4 AFM COMPONENTS

The components of the equipment required to perform AFM include fixture or tooling, the machine, abrasive laden media, Hydraulic press , Cylinder containing media , Flange, Work piece, Piston of hydraulic press, Directional control valve ,Manifold blocks etc.

In general terms, the abrasive media determines what kinds of abrasion occur, the fixture determines exact location of abrasion, and machine decides the extent of abrasion.

1.4.1 FIXTURE OR TOOLING

Fixture or tooling can be made of nylon, aluminum, steel, urethane Teflon, or a combination thereof. Aluminum and nylon are easily machinable lightweight materials. Steel is used for its strength and durability. Generally nylon fixture is mostly used.

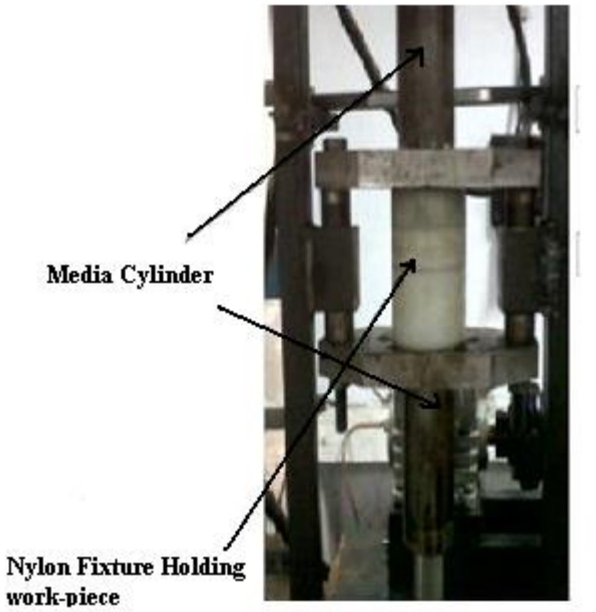


Fig 1.4 (a) AFM Fixture or tooling

Fixture design is often a very important factor in achieving the desired effects from the AFM process. Basic functions of fixture include:

- Hold the parts in position and to contain the media and directs its flow
- Protecting edges or surfaces from abrasion due to media flow by acting as a mechanical mask.
- Providing a restriction in the media flow path to control the media action in selected areas.
- Holding the parts in the proper position between the two opposed media cylinders.
- Containing the media and completing the closed-loop system required for multiple machine cycle operation without loss of media.
- Assisting, loading, unloading, or cleaning operations.
- Directing media flow to and from the areas of the part to be worked on, during the process cycle.

If AFM is used to process external edges or surfaces, the tooling contains the part in the flow passage, restricting the flow between the exterior of the part and the interior of the fixture. Any number of parallel restrictions can be processed simultaneously with uniforms results. To maximize productivity, fixture can be designed for batch production processing of many parts simultaneously if their configuration and size permit.

1.4.2 MACHINE

AFM uses two vertically opposed hydraulic cylinders, which extrude medium back and forth through passage formed by the workpiece and tooling. Abrasion occurs wherever the medium passes through the highly restrictive passage. The key components of AFM process are the machine, tooling and abrasive medium ..

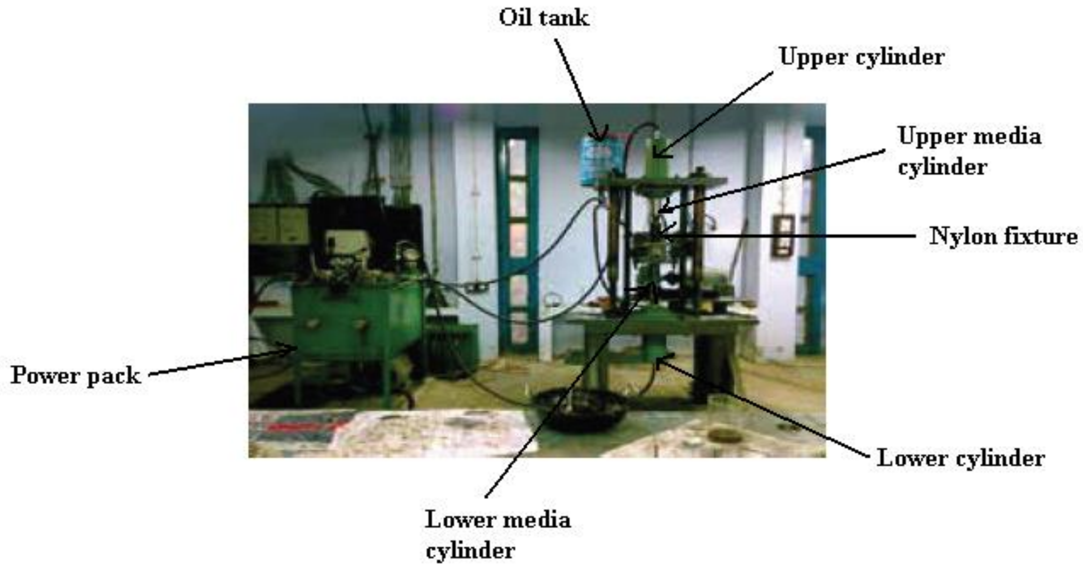


Fig 1.4 (b) AFM Machine

AFM machine controls two crucial parameters for determining the amount of abrasion, the extrusion pressure and the media flow rate. Standard units operate within 10 bar to 200 bar pressure range with flow rates up to 400 liters/min. AFM systems are essentially provided with controls on hydraulic system pressure, clamping and unclamping of fixtures, volume flow rate of abrasive media, and advance and retract of media pistons. Programmable microprocessor control unit can be used to monitor and control additional process parameters at the machine, such as media temperature, media temperature, media viscosity, abrasive wear, and flow speed. Several accessories such as part cleaning stations, automatic flow timers, cycle counters, pressure and temperature compensated flow control valves, automatic media lubricant replenishment, and media heat exchangers units may also be integrated to the conventional AFM systems for production applications [17].

1.4.3 MEDIA

Silicon based polymer with hydrocarbon gel is used for media along with Aluminium Oxide as abrasive for the present investigation. A Polymer-to-Gel (PGR) has been taken in the ratio of 1:1. Abrasives-to- media ratio is also one. Aluminium Oxide of grit size 150 can be used.

This technique uses a non-Newtonian liquid polymer containing abrasive particles of aluminum oxide, silicon carbide, boron carbide or diamond as the grinding medium and additives [18]. Abrasive particles to base material ratio can be varying from 2 to 12. Abrasive are available in different mesh sizes. The abrasive have limited life. AS a thumb rule, when the media has machined an amount equal to 10% of its weight, it must be discarded. Machined parts should be properly cleaned before use, by acetone. The additives are used to modify the base polymer to get the desired flowability and rheological characteristic of the media. Hydrocarbon gels are commonly used lubricants in the media. All additives are carefully blended in predetermined qualities to obtain consistent formulation.

1.5 HELICAL ABRASIVE FLOW MACHINE

The tooling of Helical-AFM setup has lower, middle, upper fixtures, and helical-fluted drill bit. Drill bit is attached in the inner hole of work piece and this drill bit is held stationary. Lower and upper fixtures are tapered for proper media flow. The major difference between AFM and Helical-AFM machines is its tooling. In AFM machine, circular fixture plate allows the medium to flow as' cylindrical slug. So, the abrasive intermixing (or reshuffling) purely depends on medium self-deformability. The abrasive particles follow the shortest contact length; hence, the material removal is less. In Helical-AFM, abrasive intermixing depends not only on medium self-deformability as in AFM but also on the pressure from the drill bit. In Helical-AFM, three types of flows that occur in finishing zone (Figure 1.3(a),(b),(c),) and remixing of medium at exit from the finishing zone(flow along the flute, axial flow, and scooping flow) [19]. Due to the combination of different flows, the work piece-abrasive contact length is no longer a straight line, rather it becomes curved; hence, the number of peaks that can be sheared increases, leading to higher material.

1- Flow along the flute

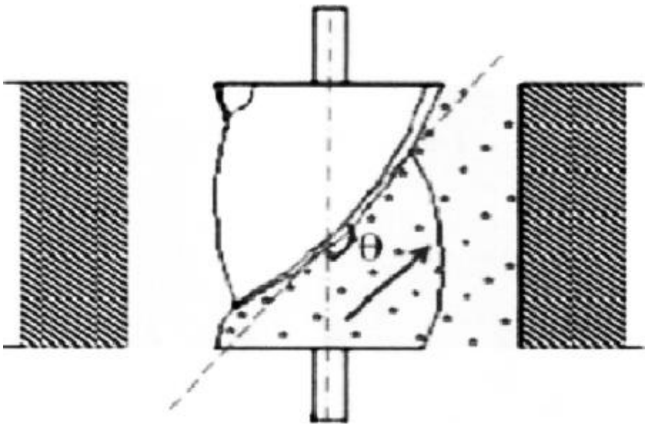


Figure 1.6(a)[19]

2- Reciprocating axial flow motio

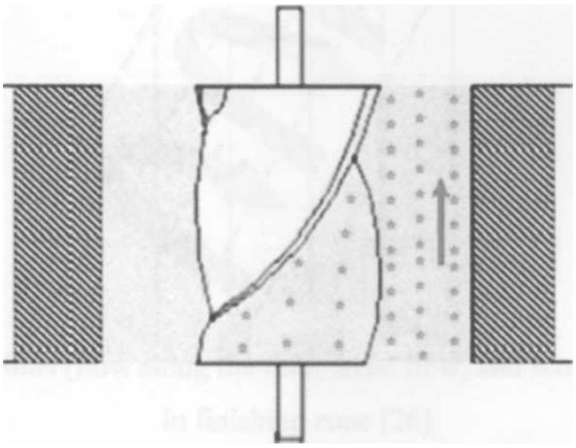


Figure 1.6 (b)[19]

3- Scooping Flow

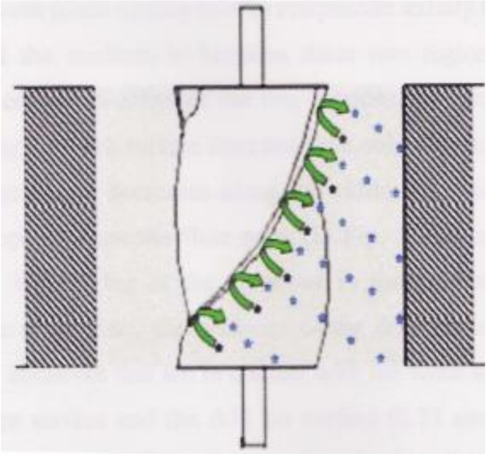


Figure 1.6(c)[19]

4- Finishing zone in Helical- AFM

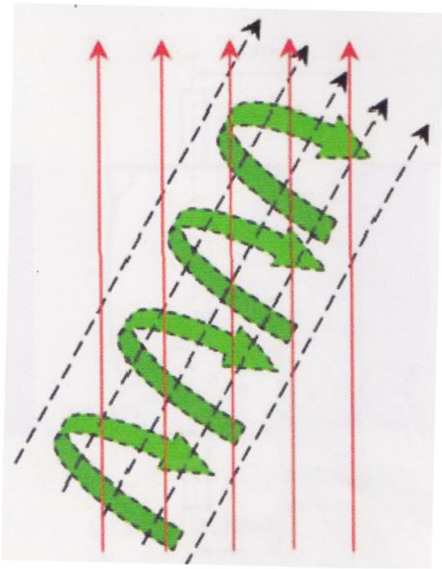


Figure 1.6 (d) [19]

Figure 1.6 (d) Three motions (flow along the flute, axial flow, and scooping flow) that can occur in finishing zone

The motion of media in the machining zone is the combinations of three kind of motion. The media near the work piece is straight reciprocating motion and the media near the flute flow along the profile of the drill bit as in case of helical profile media flow in helical path. Since the flute depth gradually decreases along its width, the medium that flows across the flute path tries to scoop out from the flute edge (in Fig. 1.3(c), shown by circular arrows). Scooping flow causes intermixing of the abrasives in the intermediate region and exterior regions of the abrasive slug. Thus, the presence of the drill bit in the finishing zone exerts additional force on the abrasives that are in contact with the work surface due to the small gap between the work piece surface and the drill bit surface (0.75 mm). The combination of all these three flows and self-deformability of the medium leads to intermixing of abrasives in the finishing region (Figure. 1.3(d)). It results in random motion of abrasives (Figure. 1.4), hence more material removal rate and high surface finish. Thus, the presence of the drill bit in the finishing zone exerts additional force on the abrasives that are in contact with the work surface due to the small gap between the work piece surface and the drill bit surface (0.75 mm). The combination of all these three flows and self-deformability of the medium leads to intermixing of abrasives in the finishing region (Figure. 1.3(d)). It results in random motion of abrasives (Figure. 1.4), hence more material removal rate and high surface finish.

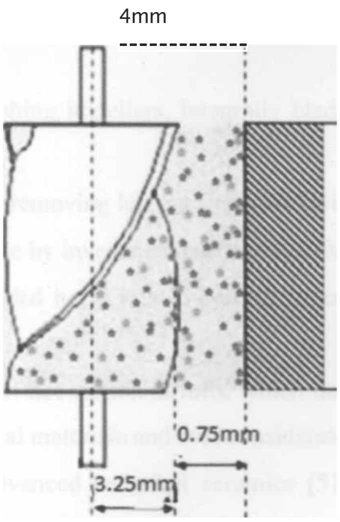


Figure l.6(e) Intermixing and Random Motion of Abrasives in Finishing Zone[19]

1.6 AFM APPLICATIONS

Helical AFM is a well established advanced finishing process capable of meeting the diverse finishing requirements from various sectors of applications like aerospace, medical and automobile. It is commonly applied to finish complex shapes for better surface roughness values and tight tolerances Helical AFM is suitable for work-pieces with complicated intersections that ask for high cost and which labor intensive is, and pose health hazards. Large surface irregularities, such as deep scratches or large bumps, cannot be removed by AFM because material is removed equally from all surfaces. Helical AFM is a well established advanced finishing process capable of meeting the diverse finishing requirements from various sectors of applications like aerospace, medical and automobile. It is commonly applied to finish complex shapes for better surface roughness values and tight tolerances For the same reason, imperfections, such as out-of-roundness and taper, cannot be corrected [20].

Some of the successful fields and applications of helical AFM are enlisted in this section:

1.6.1 Automotives

The demand for this process is increasing among car and two wheeler manufacturers as it is capable to make the surfaces smoother for improved air flow and better performance. AFM process is used to enhance the performance of high-speed automotive engines. AFM process is capable to finish automotive and medical parts, and turbine engine components . Internal passages within a turbine engine diffuser are polished to increase air flow to the combustion chamber of the engine. The rough, power robbing cast surfaces are improved from 80-90% regardless of surface complexities.

1.6.2 Dies and Moulds

Since in the AFM process, abrading medium conforms to the passage geometry, complex shapes can be finished with ease. Dies are ideal workpieces for the AFM process as they provide the restriction for medium flow, typically eliminating fixturing requirements. The uniformity of stock removal by AFM permits accurate 'sizing' of undersized precision die passages.

1.6.3 Space and Aeronautics Industry

In space and aeronautics Industry (AFM is used to remove very thin layers of coatings from the turbine blades for re-coating, and for improving the conditions of the airfoil surface made by EDM, ECM, casting, or milling, and Polishing of cast turbine blades to increase air flow). Abrasive Flow Machining will precisely remove the “recast layers” of material resulting from the thermal characteristics of laser and EDM cutting techniques in many high-strength applications. Improved surface integrity with enhanced eddy current readings result in more reliable and efficient components. Precise and repeatable edge control, regardless of configuration, typically equates to less flow resistance and enhanced cycle fatigue strength

1.6.4 Medical technology

In Medical technology (such as machining implantable devices, Finishing cannula tubes for surgical implantation, pharmaceutical machines, or a slot on a staple slide for surgical instruments used to close incisions[20].

CHAPTER 2

LITERATURE REVIEW AND PROBLEM FORMULATION

Finishing process is a very necessary process for any manufacturing industries. Finishing operation is not only time consuming but also very costly process. In some cases finishing operation is done manually. Some time manual handling causes serious health problem. Some time the mechanical parts are very complex and it is very difficult to finish such part manually by conventional methods. AFM is such process which is the right answer of above problems. This AFM process replaces a lot of manual finishing process leading to more standardization of manufactured part. Further the effectiveness of AFM can be increased by converting it in Helical abrasive flow machining.

2.1 MAJOR AREAS OF AFM RESEARCH

A lot of work has been done to study the effects of important AFM process parameters. Some the works have been reported as under:

2.1.1 Extrusion Pressure

It has been found that cutting is faster at an increased extrusion pressure, with all other parameters remaining constant. A part of total pressure is lost within the media due to its internal resistance to flow and rest is imparted to abrasion particles contacting the work piece surface [21, 22, and 23]. Jain and Jain et.al. [24] reported that at higher pressure the improvement in material removal just tends to stabilize probably due to localized rolling of abrasion particles.

2.1.2 Media Temperature

From the experimental results reported by Weller et.al. [25], it can be interpreted that an increase in temperature during processing results in faster cutting of the material, under otherwise constant cutting conditions. Jain and Jain et.al. [24] analyzed the heat flow to the work piece and the medium in AFM process. In their study Hull et.al [26] reported the effect of temperature (within the range 30-70 °c) on rheology of media used and stated that the media may sometimes undergo a permanent change in physical properties with increase in temperature.

2.1.3 Abrasives Concentration

Jain and Adsul et.al. [18] reported that initial surface roughness and hardness of the workpiece affects material removal during AFM process. Material removal and reduction in surface roughness value are reported higher for the case of softer workpiece material as compared to harder material. Material removal and reduction in surface roughness increases when percentage concentration of abrasive in the medium increases. They also concluded that among all the process parameters studied, the dominating one is the abrasive concentration followed by abrasive mesh size, and number of cycles.

2.1.4 Media Flow Volume

The media flow volume is one of the dominant process parameters in AFM for controlling the amount of abrasion and surface finish by a specific media composition. Keeping all other process parameters constant, a larger volume of media will cause more abrasion. The amount of abrasion or stock removal that occurs is directly related to the slug length of flow, which in turn is governed by media flow volume [27].

2.1.5 Media Flow Rate

Media viscosity, extrusion pressure, and passage dimension determine the media flow rate (the speed of the abrasive slug passing through the restrictive passage) which affects the uniformity of the material removal and the formation of edge radius. Rhoades et.al. [28] has reported that media flow rate is less influential parameter in respect to material removal.

2.1.6 Media Viscosity

Williams and Rajurkar et.al. [29] have reported that viscosity of the media is one of the significant parameters of the AFM process. Keeping all other parameter constant, an increase in viscosity improves both material removal and surface roughness. They used the full factorial experimental design to study the effect of medium viscosity and extrusion pressure on metal removal and surface roughness. Medium's viscosity effect is more significant on material removal as compared to extrusion pressure. It is also reported that major change in the surface finish is observed after finishing for a few cycle only.

2.1.7 Number of Process Cycles

A number of cycles are required to achieve the desired surface finish and material removal. It has been reported in a number of studies that abrasion is more pronounced in some initial cycles after which improvement in the surface finish stabilize or reduce in some cases [29]. Total number of process cycles range from one to several hundred . Within 1 to 8 cycles, a linear dependence between material removal and surface roughness versus number of cycles was indicated. In AFM the forward and backward extrusion back to the initial stage completes a cycle.

2.1.8 Media Temperature

From the experimental results reported by Weller et.al. [30], it can be interpreted that an increase in temperature during processing results in faster cutting of the material, under otherwise constant cutting conditions. Jain and Jain et.al. [18] analyzed the heat flow to the work piece and the medium in AFM process. In their study Hull et.al [31] reported the effect of temperature (within the range 30-70 °c) on rheology of media used and stated that the media may sometimes undergo a permanent change in physical properties with increase in temperature.

2.1.9 Abrasive Particle Size

Sizes of abrasive particles used in AFM process range from #8 grit (roughing and stock removal application) to #500 grit (small hole application). Smaller size abrasive gives better surface finish and can reach into complex and narrow passages, while larger one cut faster. According to one thumb rule [31] finer abrasives should be used when the initial roughness of the work surface is less. The reason for a decrease in material removal is that with an increase in mesh size (or decrease in grain size in mm) the depth of penetration as well as width of penetration, decreases.

2.1.10 Material and Geometric Feature of Workpiece

The nature of surface generated by AFM process is reported by Loveless et.al. [32] to differ significantly from the surfaces produced by other processes. The improvement in surface finish by AFM is also shown to be significantly affected by the type of prior machining process carried out on the work piece. Jain and Adsul et.al. [18] in their study mentioned that material removal is governed by initial surface roughness and work piece hardness. Softer material has higher material removal and more improvement in surface finish as compared to harder material. Generally, work piece with single hole has been taken for processing but an investigation has also been carried on multiple holes specimen [33]. It was observed that for a multiple hole specimen with one centre hole and four outer holes, the central hole experiences 30% more material removal. This has been explained by suggesting a non-uniform velocity distribution of media while flowing through a multiple-hole work piece. Further, it has been reported by Przyklenk et.al. [34] that as the media takes the least resistance path, it tends to flow through the major bores even if they are not situated in centre but are staggered.

In case when processing parallel passage, the larger cross section passage receives more abrasion Jain and Jain et.al. [24] defined the "Reduction Ratio" as the difference between cross sectional area media cylinder and that of extrusion passage divided by the cross sectional area of media cylinder. For a specified number of cycles, it has been observed that the more the reduction ratio the more will be the material removal from the work piece.

2.2 IMPROVEMENT IN AFM

2.2.1 Magnetic field assisted abrasive based micro finishing

Jha and Jain et.al. [18] analyzed that it is possible to externally control the forces acting on the work piece by varying D.C. electric current flowing in the electromagnet coil or by changing the working gap while using a permanent magnet. A change in the electric current changes megnetic flux density in the working zone due to which the normal force exerted by an abrasive particle on the work piece changes. This change in normal force changes finishing rate ire critical surface finish that can be achieved by the process under the given finishing conditions.. This class of processes is capable to produce surface roughness value of 8 nm or lower.

2.2.2 Rotating Drill Bit and Stationary Workpiece AFM

In order to enhance productivity of the process, Mondal and Jain et.al. [35] has been introduced a concept of rotating the media along rotated drill bit axis to achieve higher rate of finishing and material removal. This process is termed as drill bit-guided abrasive flow finishing (DBG-AFF) process. In order to provide random motion to the abrasives in the medium and to cause frequent reshuffling of the medium, the medium is pushed through a helical rotated fluted drill, which is placed in the finishing zone.

2.2.3 Rotating Work piece and Stationary Drill Bit AFM

It has been studied by Jain & Sankar et.al. [36] that in drill type AFM, abrasive intermixing depends not only on medium self-deformability as in AFM but also on the pressure from the drill bit, three types of flows (flow along the flute, reciprocating axial flow motion, and scooping flow) that occur in finishing zone and remixing of medium at exit from the finishing zone. Due to the combination of different flows, the work piece-abrasive contact length is no longer a straight line, rather it becomes curved; hence, the number of peaks that can be sheared increases, eading to higher material (finishing rate also improves compared to AFM process. The gap between the work piece surface and the drill bit was varied by changing drill bit diameter and geometry. Increase in drill bit diameter provides more surface finish.

2.2.4 Centrifugal forced Abrasive Flow Machining

From experimental results by Walia and Shan et.al. [6] it can be seen that addition of centrifugal force with help of external guided arrangements in media increase improvement in surface lish and material removal rate. A rotating Centrifugal Force Generating (CFG) rod was used inside the cylindrical work piece, which provides the centrifugal force to the abrasive particles normal to the axis of work piece.

2.3 PROBLEM FORMULATION

In the present research work a three star helical drill bit is used coaxially with in the hollow cylindrical workpiece using three piece nylon fixture . The developed Helical-Abrasive flow machining process employs a standard helical drill-bit, which forces the abrasives laden media to follow a helical path within the finishing zone Curvature in the path of abrasives laden media, leads to development of centrifugal forces in the media in addition to a combination of different media flows (flow along the flute, axial flow, and scooping flow, and remixing of medium at exit from the finishing zone. Helical Abrasive Flow Machining is a non-conventional finishing process that deburrs and polishes by forcing an abrasive media (elastic/viscoelastic polymer) across the work piece surface.

Abrasion occurs only where the media flow is restricted; other areas remain unaffected. The process embraces a wide range of feasible applications from critical aerospace and medical components to high-production volumes of parts. One serious limitation of this process is its low productivity in terms of rate of improvement in surface roughness. Efforts have hitherto been directed towards enhancing the productivity of this process with regard to better quality of work piece surface.

The present research work focuses on the development of a modified Helical- AFM (HLX-AFM) setup for better material removal and high surface finish for ductile materials reported as under:

2.4 PROPOSED RESEARCH

This research focuses mainly on the following issues related to the development of Helical AFM Setup:

2.4.1 Design and setup for Helical-AFM

A basic AFM setup for a maximum media pressure of 25N/mm^2 can be used. AFM setup, there are two hydraulic and two media cylinders to be placed vertically in the present case. It is desired to extrude abrasives laden media up and down through the nylon care and work-piece with the help of these cylinders. The media is to be extruded at different flow rate and at different pressures. Once one extrusion stroke is complete the process is to be reversed by maintaining the same pressure combinations with least possible hydraulic controls. There is a provision of removing of nylon fixtures from the machine.

The basic AFM setup has been modified for the Helical-AFM by designing new fixturing holding a drill bit stationary inside the hollow cylindrical work piece.

2.4.2 Performance Improvement and Testing of developed setup

Though AFM is a metal finishing technique, material removal and surface finish play significant roles in providing the final surface finish to the component. In the Helical-AFM a combination of axial, radial, centrifugal forces and media movements take place. This results in more material removal and better surface finish.

2.5 OBJECTIVES OF THE PRESENT INVESTIGATION

In light of the above-mentioned proposal, the present investigation aims to explore the following objectives:

- Optimize the important process parameters like type of materials, extrusion pressure, no.of cycle for the internal finishing of brass, mild steel and gun metal specimens and experimental study of the effect of various process parameters on the performance characteristics of these above materials.
- Use of stationary drill-bit in the internal finishing to improve material removal in case of brass, gun metal and mild steel specimens

CHAPTER-3

DEVELOPED HELICAL -AFM SETUP

The developed Helical-Abrasive flow machining process employs a standard helical drill-bit, which forces the abrasives laden media to follow a helical path within the finishing zone.. In the Two-way AFM process, there are two hydraulic and two media cylinders to be placed vertically. It is desired to tide abrasives laden media up and down through the nylon fixture and work-piece with the help of these cylinders.

3.1 SCHEMATIC OF HELICAL-AFM PROCESS

A drill-bit of length 95mm, diameter 6.5 mm and Flute length 65 mm is used. The heel of the drill-bit has been grounded and the effective outside diameter is 5.8 mm. During the upward and download stokes, initially drill-bit rotates, gets lifted or moves down, and then randomly orients itself in a fixed position for the rest of the working stroke with the help of upper and lower locking pins respectively.

The pressurised media passes through drill bit causes a braiding of the work piece. Due to stationary drill bit, three types of flows (axial flow, reciprocating flow and scooping flow) and froces (axial, radial and centrifugal forces) that occur in finishing zone and remixing of medium at exit from the finishing zone [19] in Helical-AFM process. Due to the combination of different flow and forces, the work piece-abrasive contact length is no longer a straight line, rather it becomes curved; hence, the number of peaks that can be sheared increases, leading to higher material. In Helical- AFM process rolling, ploughing and indentation of the abrasive grains is me to motions and forces as shown in figure 3.1.

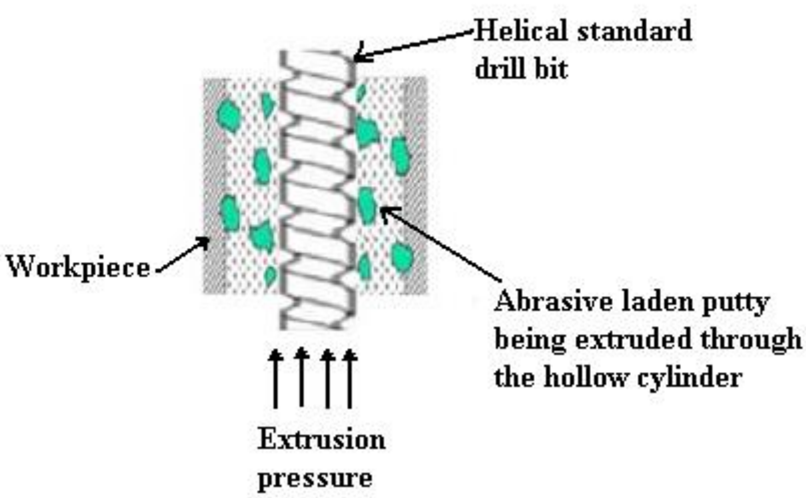


Figure3.1 Schematic of Helical-AFM Process

3.2 DEVELOPMENT OF HELICAL- AFM

Helical-AFM can be divided into two elements:

- Development of Helical-AFM fixture
- Abrasive laden media

Existing setup uses two hydraulic actuators of inner diameter 130mm and two media cylinder of inner diameter 63mm of volume 290cm^3. The media is to be extruded at different pressures, media flow rates, media flow volume, stroke length and a number of cycles are required to operate the system with as without stationary drill bit. The hydraulic drive is capable of reversing the process, once one extrusion stroke is complete by maintaining the same pressure combinations with least possible hydraulic controls. An appropriate frame and housing is available to accommodate the system.

3.2.1 Development of Improved Fixturing for Helical-AFM

Fixturing concept largely depends upon the work-piece material and configuration. For the -resent investigation, work-piece is a hollow cylindrical test specimen, classified as sleeve type component. The fixture is made in three parts. The work-piece is held between first and second, at the interface of two parts and the fixtures plates are clamped together with the help of three countersunk screws allowing the passage (in the work-piece) itself to form the greatest restriction in the media flow path. The threaded holes were kept blind to avoid the possible ingress of abrasive media. The material of the fixture used was Nylon. Good shearing strength, ear resistance, and light weight made Nylon a good candidate for the fixture material.

(a) Nylon Fixture Part-1

The first part of fixture is a 102mm diameter piece of nylon. This is the topmost nylon fixture part and hold work piece in place. Fixture has a converging conical mouth at the top which facilitates the media flow into the work piece as show in fiure3.2. An improved fixture has been developed with a provision for holding a drill bit axially inside the hollow cylindrical work piece. The drill bit is held stationary and during the different strokes will randomly: rented itself inside the work piece.

Figure 3.2 Nylon Fixture Part-1

(b)Nylon Fixture Part-2

Second part of fixture is also a 102 mm diameter piece of nylon. It holds the work piece at top along with Nylon Fixture Part-1 and has a passage for the flow of media as shown in figure 5.3. On the bottom side it is attached to Nylon Fixture Part-3. The drill bit is held axially mostly inside this part and to this HLX-AFM Part-3 which is a M.S. disc with holes for drill and media is fixed.

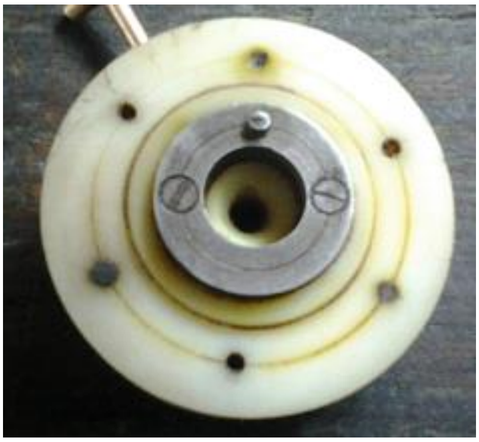


Figure 3.3 Nylon Fixture Part-2

(c) Nylon Fixture Part-3

Third part of the fixture is also made of nylon. Its diameter is 120 mm. this is the bottom most part with a cylindrical bore inside it (figure 3.). Inside the cylindrical bore the drill bit assembly can slide freely. It also has a component AFM Part-5 attached at the bottom of cylindrical bore stop the drill bit at any random orientation. At the bottom it, a converging conical mouth similar to the first part at top.

Figure 3.4 Nylon Fixture Part 3

(d) Drill-Bit Axial Restraining Disc

This is mild steel disc of 40 mm diameter, 4 mm width (Figure 3.5). It is tightly fitted in the first part of the fixture with the help of screws. Its key function is to hold the drill bit at centre of the work piece during the flow of media. It contains holes at centre and circumference required to keep drill axially and for the flow of media.

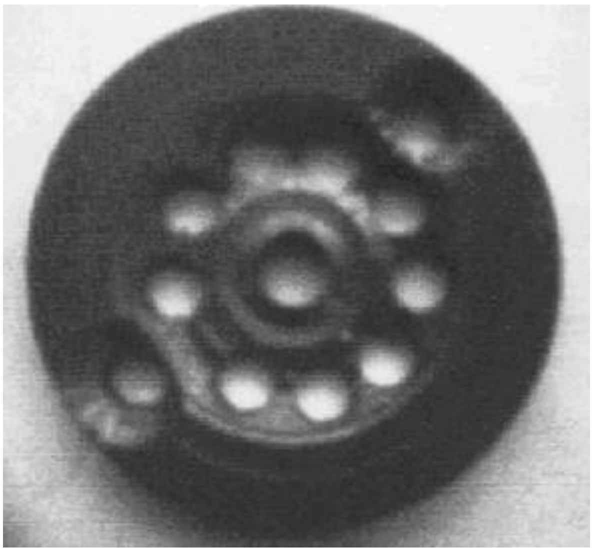


Figure 3.6 Mild Steel Discs

(e) Mild Steel disc (2 Numbers)

Disc-2 is a Mild Steel disc with 48 mm outer diameter, 25 mm inner diameter and a width of 10 mm (figure3.6). It is fixed in the second part of the fixture with the help of two screws. It is fitted with a tight fit cylindrical key. When media flows upwards, it fits into one of the holes drilled in the outer periphery of the drill disc (disc on which drill bit is mounted) as a result of which the drill stays in place and the flow of media remains uniform when the media is flowing upwards this disc is attached at the bottom of cylindrical bore inside nylon part-3.

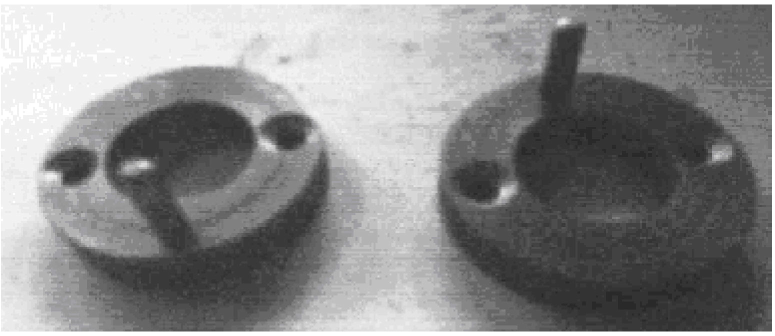


Figure 3.6 Mild Steel Discs

(f) Drill Bit Disc

This is slide fit inside the cylinder bore and can move up or down and rotate freely. It is a mild steel disc. Its diameter is 48 mm and width 15 mm. unlike other three discs, this disc is movable. At its centre a drill bit of length 95mm, diameter 6.5 mm and Flute length 65 mm is welded (Figure 3.7). This disc is a slide fit disc and rests just above the second key disc in the third part of the fixture. The cutting edges of the flute are grounded in order to avoid any damage to the internal surface of the work piece while going up and down.

At its outer periphery there are holes which fit into one of the keys when the media is flowing, in order to stabilize itself and hold drill bit in place. At inner periphery holes are drilled to allow the flow of working media through the disc.

Figure 3.7 Three start drill bit disc

3.3 Abrasive Laden Media

Media used for present investigation consists of silicon based polymer, hydrocarbon gel and abrasive particles. The polymer was prepared by a special technique, for which a patent was granted. The gel was prepared by reacting aluminum striate with hydrocarbon oil. The gel was then mixed into the polymer in a suitable proportion by vigorous kneading. The mixture of the polymer and gel was used as a carrier compound in the media. In the present work, the abrasive particles of Aluminum Oxide of grit size 200 were used.

CHAPTER 4

EXPERIMANTAL DESIGN AND ANALYSIS

Design of experiment is considered to be a very useful strategy for accomplishing a properly planned and executed experiment for accurate conclusions from the experimental observations. Design of experiments (DOE) or experimental design is the design of any information-gathering exercises where variation is present, whether under the full control of the experimenter or not. However, in statistics, these terms are usually used for controlled experiments.The science of statistical experimental design originated with the work of Sir Ronald Fisher in England in 1920s. Fisher founded the basic principle of experimental design and the associated data-analysis technique called Analysis of Variance (ANOVA) during his efforts to improve the yield of agricultural crops [37]. The theory and applications of experimental design and the related technique of *response surface methodology* have been advanced by many statistical researchers as Box and Hunter [21], Box and Draper [38]

.While designing the experiments for the present study the following DOE techniques have been used :

4.1 TAGUCHI'S EXPERIMENTAL DESIGN AND ANALYSIS

In the traditional, one-variable-at-a-time approach, only one variable at a time is evaluated keeping remaining variables constant during a test run. This type of experimentation reveals the effect of the chosen variable on the response under certain set of conditions. The major disadvantage of this approach is that it does not show what would happen if the other variables are also changing simultaneously. This method does not allow for study of the effect of the interaction between the variables on the response characteristic. The interaction is the failure of one factor to produce the same effect on the response at different levels of another variable [40]. On the other hand, full-factorial designs require experimental data for all the possible combinations of the factors involved in the study; consequently a very large number of trial need to be performed. Therefore, in the case of experiments involving relatively more number of factors, only a small fraction of combinations of factors are selected that produces most of the information to reduce experimental effort. This approach is called fractional-factorial design of experiment. The analysis of results in this approach is complex due to non-availability of generally accepted guidelines. The Taguchi method provides a solution this problem.

4.1.1 Taguchi's Philosophy

Taguchi's comprehensive system of quality engineering is one of the great engineering achievements of the 20th century. His methods focus on the effective application of engineering strategies rather than advanced statistical techniques. It includes both upstream and shop-floor quality engineering. Upstream methods efficiently use small-scale experiments to reduce ability and remain cost-effective, and robust designs for large-scale production and marketplace. Shop-floor techniques provide cost-based, real time methods for monitoring and maintaining quality in production. The farther upstream a quality method is applied, the greater leverages it produces on the improvement, and the more it reduces the cost and time. Taguchi's philosophy is founded on the following three very simple and fundamental concepts [39,40]:

- Quality should be designed into the product and not inspect into it.
- Quality is the best achieved by minimizing the deviations from the target. The product or process should be so designed that it is immune to uncontrollable environmental variables.
- The cost of quality should be measured as a function of deviation from the standard and the losses should be measured system-wide.

Taguchi's proposes an "off-line" strategy for quality improvement as an alternative to an attempt to inspect quality into a product on the production line. He observes that poor quality cannot be improved by the process of inspection, screening and salvaging. No amount of inspection can put quality back into the product. Taguchi recommends a three-stage process: *system design*, *parameter design* and *tolerance design* [41]. In the present work Taguchi's parameter design approach is used to study the effect of process parameters on the material removal, surface finish in Helical AFM process.

4.1.2 Experimental Design Strategy

Taguchi recommends orthogonal arrays (OA) for laying out of experiments. These OA's are generalized Graeco-Latin squares. To design an experiment is to select the most suitable OA and to assign the parameters and interactions of interest to the appropriate columns. The use of linear graphs and triangular tables suggested by Taguchi makes the assignment of parameters simple. The array forces all experimenters to design almost identical experiments [42].

In the Taguchi method the results of the experiments are analyzed to achieve one or more of the following objectives :

- To estimate the best or the optimum condition for a product or process.
- To estimate the contribution of individual parameters and interactions.
- To estimate the response under the optimum condition.

The optimum condition is identified by studying the main effects of each of the parameters. The main effects indicate the general trend of influence of each parameter. The knowledge of contribution of individual parameters is a key in deciding the nature of control to be established on a production process. The analysis of variance (ANOVA) is the statistical treatment most commonly applied to the results of the experiments in determining the percent contribution of each parameter against a stated level of confidence. Study of ANOVA table for a given analysis helps to determine which of the parameters need control .

Taguchi suggests [42] two different routes to carry out the complete analysis of the experiments. First the standard approach, where the results of a single run or the average of the repetitive runs are processed through main effect and ANOVA analysis (Raw data analysis). The second approach which Taguchi strongly recommends for multiple runs is to use signal-to-noise (S/N) ratio for the same steps in the analysis. The S/N ratio is a concurrent quality metric linked to the loss function. By maximizing the S/N ratio, the loss associated can be minimized. The S/N ratio determines the most robust set of operating conditions from variation within the results. The S/N ratio is treated as a response parameter (transform of raw data) of the experiment. Taguchi recommends the use of outer OA to force the noise variation into the experiment i.e. the noise is intentionally introduced into the experiment. Generally, processes are subjected to many noise factors that in combination strongly influence the variation of the response. For extremely 'noisy' systems, it is not generally necessary to identify controllable parameters and analyze them using an appropriate S/N ratio [43]. In the present investigation, both the analysis: the raw data analysis and S/N data analysis have been performed. The effects of the selected Helical AFM parameters on the selected quality characteristics have been investigated through the plots of the main effects based on raw data. The optimum condition for each of the quality characteristics have been establish through S/N data analysis. No outer array has been used and instead, experiments have been repeated three times at each experimental condition.

4.1.3 Loss Function and S/N Ratio

The heart of Taguchi method is his definition of nebulous and elusive term *'quality'* as the characteristic that avoids loss to the society from the time the product is shipped [44]. Loss is measured in terms of monetary units and is related to quantifiable product characteristics. Taguchi defines quality loss via his 'loss-function'. He unites the financial loss with the functional specification through a quadratic relationship that comes from Taylor series expansion [49].

$$L(y) = k(y-m)^2$$

where, L = loss in monetary unit

m = value at which the characteristic should be set

y = actual value of the characteristic

k = constant depending on the magnitude of the characteristic and the monetary unit involved.

The traditional and the Taguchi loss function concept have been illustrated in Figure4.l (a) and Figure 4.1(b). The following two observations can be made from Figure 4.1 (a, b) [44].

- The further the product's characteristic varies from the target value, the greater is the loss. The loss is zero when the quality characteristic of the product meets its target value.
- The loss is a continuous function and not a sudden step as in the case of traditional approach (Figure4.1b).

This consequence of the continuous loss function illustrates the point that merely making a product within the specification limits does not necessarily mean that product is of good quality.

In a mass production process the average loss per unit is expressed as:

$$L(y) = \{k(y_1-m)^2 + k(y_2-m)^2 + ... + k(y_n - m)^2\} \quad (4.1)$$

where

y 1 , y2 .... y_n = values of characteristics for units 1,2,........n respectively

n = number of units in a given sample

k = constant depending upon the magnitude of characteristic and the monitory unit involve

m= Target value at which characteristic should be set.

Equation (5.1) can be written as:

$$L(y)=k(MSD)$$

Where MSD denotes mean square deviation, which presents the average squares of all deviations from the target value rather than around the average value.

Taguchi transformed the loss function into a concurrent statistic called S/N ratio, which combines both the mean level of the quality characteristic and variance around this mean into a single metric. The S/N ratio consolidates several repetitions (at least two data points are required) into one value. A high value of S/N ratio indicates optimum value of quality with minimum variation. Depending upon the type of response, the following three types of S/N ratio are employed in practice .

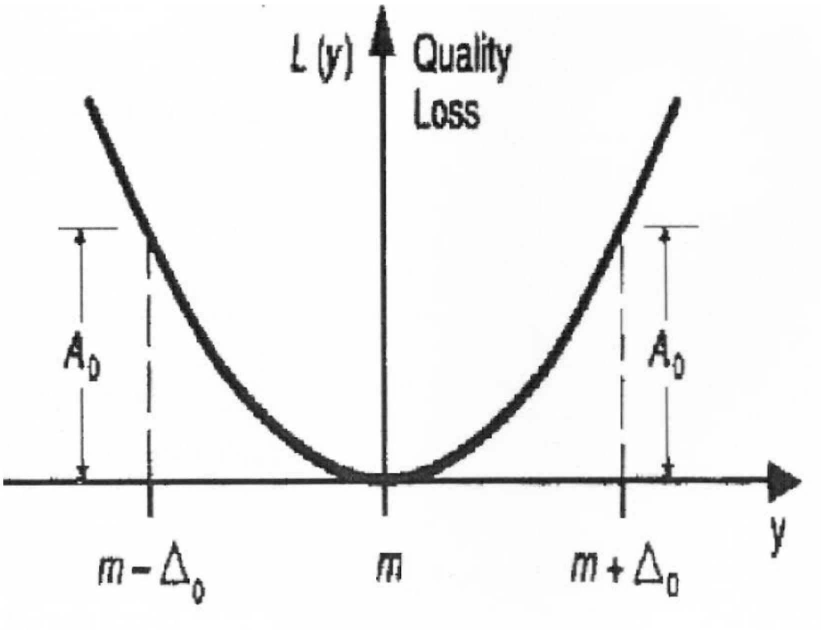


Figure 4.1 (a) Taguchi Loss Function

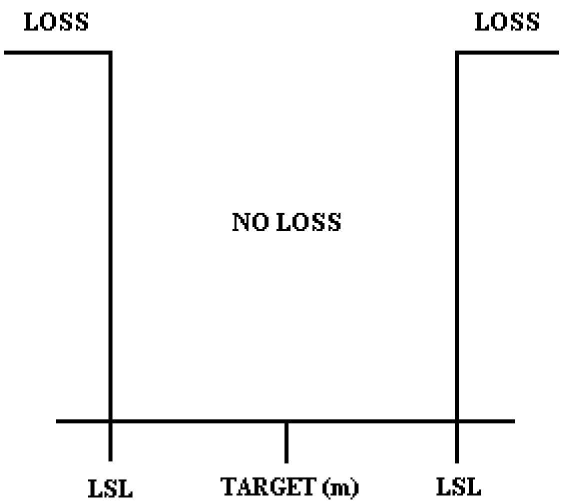


Figure 4.1 (b) Traditional

1. Larger the better :

   $(S/N)_{HB}$ = -10 log (MSD_{HB}) (4.2)

   Where

MSD HB =

$$\frac{1}{2}\sum_{j=1}^{R}(\frac{12}{yj})$$

2. Lower the better :
   $(S/N)_{LB}$ = -10 log (MSD $_{LB}$) (4.3)

   Where

   MSD LB = 1/R $\sum_{j=1}^{R}(y21)$

3. Nominal the best :
   $(S/N)_{LB}$ = -10 log (MSD $_{NB}$) (4.4)

   Where

   MSD $_{NB}$ =

$$\frac{1}{R}\sum_{j=1}^{R}(y_j - y_0)^2$$

R = Number of repetitions

It is to be mentioned that for nominal the best type of characteristic, the standard definition of MSD has been used. For smaller the better type the target value is zero. For larger the better type, the inverse of each large value becomes a small value and again the target value is zero. Therefore, for all the three expressions the smallest magnitude of MSD is being sought. The constant 10 has been purposely used to magnify S/N number for each analysis and negative sign is used to set S/N ratio of larger the better relative to the square deviation of smaller the better.

4.2.4 Taguchi Procedure for Experimental Design and Analysis

Figure 5.2 illustrates the stepwise procedure for Taguchi experimental design and analysis. It is described in the following paragraphs.

(a) Selection of OA

In selecting an appropriate OA, the following prerequisites are required:

- Selection of process parameters and/or their interactions to be evaluated.

- Selection of number of levels for the selected parameters.

The determination of parameters to investigate, upon which hinges the product or process performance characteristics or responses of interest [44]. Several methods are suggested by Taguchi for determining which parameters to include in an experiment. These are [44]:

- Brainstorming
- Flow charting
- Cause-effect diagrams

The total degrees of freedom (DOF) of an experiment are a direct function of total number of trials. If the number of levels of a parameter increases, the DOF of the parameter also increase because the DOF of a parameter is the number of levels minus one.

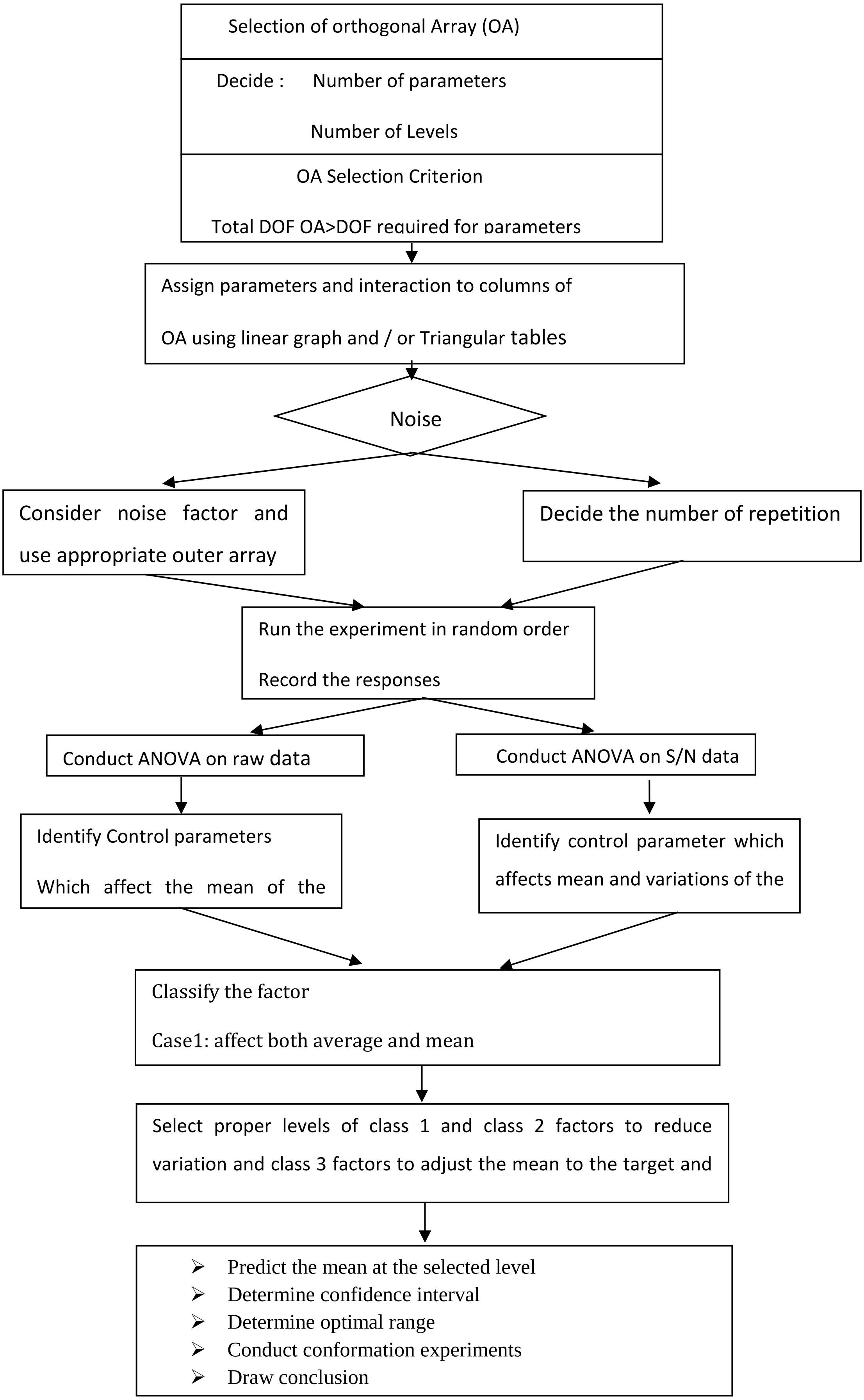


Figure 4.2 Taguchi Experimental Design and Analysis[44]

Thus, increasing the number of levels for a parameter increases the total degrees of freedom in the experiment which in turn increases the total number of trials. Thus, two levels for each parameter are recommended to minimize the size of the experiment [44]. If curved or higher order polynomial relationship between the parameters under study and the response is expected, at least three levels for each parameter should be considered . The standard two-level and three-level arrays are

a) Two-level arrays: L_4, L_8, L_{12}, L_{16}, L_{32}

b) Three-level arrays: L_9, L_{18}, L_{27}

The number as subscript in the array designation indicates the number of trials in that array. The degree of freedom (DOF) available in an OA is:

f_{LN} = N-1

Where f_{LN} = total degrees of freedom of an OA

L_N =OA designation N = number of trials

When a particular OA is selected for an experiment, the following inequality must be satisfied [59]:

$f_{LN} \geq$ Total DOF required for parameters and interactions.

Depending on the number of levels in the parameters and total DOF required for the experiment, a suitable OA is selected.

(b)Assignment of parameters and interactions to OA

An ‘OA’ has several columns to which various parameters and their interactions are assigned. Linear graphs and Triangular tables are two tools, which are useful for deciding the possible interactions between the parameters and their assignment in the columns of ’OA’. Each ‘OA’ has its particular liner graphs and interaction tables .

(c) Selection of outer array

Taguchi separates factors (parameters) into two main groups:

- Controllable factors
- Noise factors

Controllable factors are factors that can easily be controlled. Noise factors, on the other hand, are nuisance variables that are difficult, impossible, or expensive to control . The noise factors are responsible for the performance variation of a process. Taguchi recommends the use of outer array for noise factors and inner array for the controllable factors. If an outer array is used the noise variation is forced into the experiment. However, experiments against the trial condition of the inner array may be repeated and in this case the noise variation is unforced in the experiment. The outer array, if used will have the same assignment considerations.

(d) Experimentation and data collection

The experiment is performed against each of the trial conditions of the inner array. Each experiment at a trial condition is repeated simply (if outer array is not used) or according to the outer array (if used). Randomization should be carried for to reduce bias in the experiment.

(e) Data analysis

A number of methods have been suggested by Taguchi for analyzing the data: observation method, ranking method, column effect method, ANOVA, S/N ANOVA, plot of average responses, interaction graphs, etc. [44]. In the present investigation, following methods are used.

- Plot of average response curves
- ANOVA for raw data
- ANOVA for S/N data

The plot of average responses at each level of a parameter indicates the trend. It is a pictorial representation of the effect of a parameter on the response. Typically, ANOVA for OA's are conducted in the same manner as other structured experiments [44]. The S/N ratio is treated as a response of the experiment, which is a measure of the variation within a trial when noise tors are present. A standard ANOVA is conducted on S/N ratio, which identified the significant parameters.

(f)Parameter design strategy

Parameter classification and selection of optimal levels

OVA of raw data and S/N ratio identifies the control factors, which affect the average Kponse and the variation in the response respectively. The control factors are classified into four groups:

Group I : Parameters, which affect both average and variation

Group II : Parameters, which affect variation only

Group III : Parameters, which affect average only

Group IV : Parameters, which affect nothing

The parameter design strategy is to select the suitable levels of group I and II parameters to reduce variation and group III parameters to adjust the average values to the target value. The group IV parameters may be set at the most economical levels.

Prediction of mean

After determination of the optimum condition, the mean of the response (u) at the optimum condition is predicted. This mean is estimated only from the significant parameters. The ANOVA identifies the significant parameters. Suppose, parameters A and B are significant and A2B2 (second level of both A and B) is the optimal treatment condition. Then, the mean at the optimal condition (optimal value of the response characteristic) is estimated as:

$$\mu = T + (a_2\text{-}t) + (b_2\text{-}t)$$

$$= A_2+B_2-T$$

T= overall mean of the response

A_1 B_2= average values of response at the second levels of parameters A and B respectively

It may sometimes be possible that the predicated combination of parameter levels (optimal treatment condition) is identical to one of those in the experiment. If this situation exits, then the most direct way to estimate the mean for that treatment condition is to average out all the results for the trials which are set at those particular levels [44].

Determination of confidence intervals

The estimate of the mean (p) is only a point estimate based on the average of results obtained from the experiment. It is a statistical requirement that the value of a parameter should be predicted along with a range within which it is likely to fall for a given level of confidence.

This range is called confidence interval (CI). Taguchi suggests two types of confidence intervals for estimated mean of optimal treatment conditions.

- CI_{CE} - Confidence Interval (when confirmation experiments (CE)) around the estimated average of a treatment condition used in confirmation experiment to verify predictions. Get; is for only a small group made under specified conditions.
- CI_{POP} - Confidence Interval of population; around the estimated average of a treatment condition predicted from the experiment. This is for the entire population i.e. all parts made under the specified conditions.

The confidence interval of confirmation experiments (CI_{CE}) and of population (CI_{POP}) is calculated by using the following equations :

$$CI_{CE} = \sqrt{F_a\,(1, f_e)V_e\,\left[\frac{1}{n_{eff}} + \frac{1}{R}\right]} \qquad (4.5)$$

$$CI_{POP} = \sqrt{\frac{F_a\,(1,f_e)V_e}{n_{eff}}} \qquad (4.6)$$

where

F_{α} (l, f_e) = The F-ratio at the confidence level of (1-α) against DOF 1 and error degree of freedom f_e., f_e = error DOF, N = Total number of result, R = Sample size for confirmation experiments, V_e = Error variance,

$$n_{eff} = \frac{N}{1 + [DOF\ associated\ in\ the\ estimate\ of\ mean\ responce]}$$

Confirmation experiment

The confirmation experiment is the final step in verifying the conclusions from the previous round of experimentation. The optimum conditions are set for the significant parameters (the insignificant parameters are set at economic levels) and a selected number of tests are run under specified conditions. The average values of the responses obtained from confirmation experiments are compared with the predicted values. The average values of the response characteristic obtained through the confirmation experiments should be within the 95% confidence interval, $CI_{CE.}$ However, these may or may not be within 95% confidence interval, CI_{POP}. The confirmation experiment is a crucial step and is highly recommended to verify the experimental conclusions [44].

CHAPTER 5

PROCESS PARAMETER SELECTION AND EXPERIMENTATION

In the present chapter, the main process parameters, which may affect the machining characteristics such as material removal and surface finish, are selected. The scheme of experiments is also discussed in this chapter. The experiments were conducted within the ranges of selected process parameters which includes different type of drill bit, no of cycle, and different extrusion pressure. Material removal and surface finish were measured. The measured data are also provided in this chapter.

5.1 SELECTION OF PROCESS PARAMETERS AND THEIR RANGES

In order to obtain high material removal and better quality of surface produced by drill bit assisted AFM, the optimum level of drill bit assisted AFM need to be determined. Based on the critical review of literature, process variables of the drill bit assisted AFM were grouped in the following three categories:

- **The Machine Based Parameters:** media flow rate, media flow volume, extrusion pressure, and number of process cycles.
- **The Media Based Parameters:** Viscosity and temperature of media, abrasive concentration, grain size and shape.
- **The Work-piece/Fixture Based Parameters:** material of work piece, L/D ratio of media flow passage, reduction ratio, and initial surface roughness of work piece and type of drill bit (spline, two star helical, three star helical)

All the above parameters are likely to affect the material removal and surface quality produced by the drill bit assisted AFM

The range of the process parameters was decided on the basis of literature.

5.1.2. Type of material

The different types of material ductile and britlle can be used as a work piece material for experimentation with Helical AFM .In the present experiment three ductile materials viz Brass, Gun metal, and Mild steel are used .It has been found that the material which soft in nature compare to other material will give better surface finish.

5.1.1. Extrusion Pressure

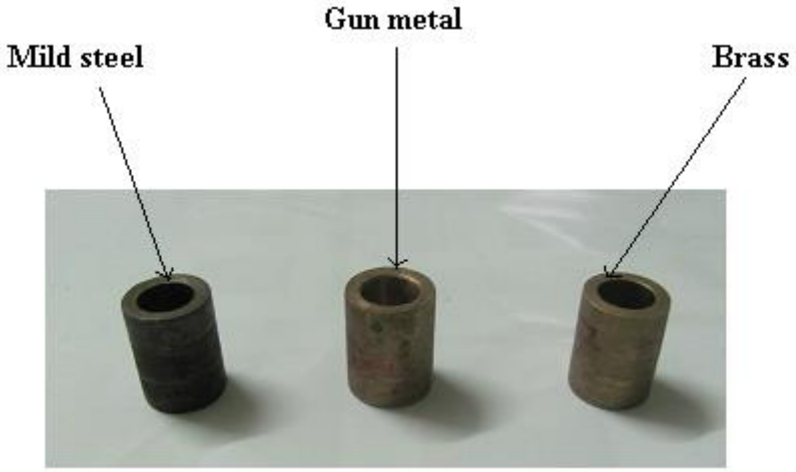
It has been found that cutting is faster at an increased extrusion pressure, with all other parameters remaining constant, at higher pressure the improvement in material removal just tends to stabilize probably due to localized rolling of abrasion particles. The relatively steady rise in *Ra* with increase in the extrusion pressure may be attributed to the increased fractional drag force due to the Non-Newtonian nature of the media which in turn reduces the net abrading force. In the present study the extrusion pressure has been kept in the range of 3-7 N/mm^2. Thought the setup maximum extrusion pressure capacity is 25 N/mm^2.

5.1.2. Number of Process Cycles

It is noticed from the literature that the material removal rapidly increases during the initial cycles and their rate of increase reduces at higher number of cycles. This is due to the fact that higher peaks are removed during the initial process cycles when abrasive particles abrade these peaks; later the peaks become somewhat flatter and the rate of material removal and that of *Ra* reduce. The greater the number and height of the peaks, the more will be the material removal by the process. However, as the surface is subjected to repeated process cycles, the number of peaks and their heights continue to decrease, and hence the material removal rate declines after a few cycles. The range of the number of process cycles have been selected from 2-12.

5.1.11. Work-piece

In the present investigation, Brass, Gun metal, and Mild steel are used as work-piece material. The cavity to be machined in the test specimen was prepared by drilling operation followed by boring to the required size.



The size of cylindrical work piece is of length 15 mm, internal and external diameters are 8 and 12.6 mm as shown in figure 5.1. The internal cylindrical surface was finished by Helical-AFM process. Each work-piece was machined for a predetermined number of cycles. The work-piece was taken out from the setup and cleaned with acetone before the subsequent measurement.

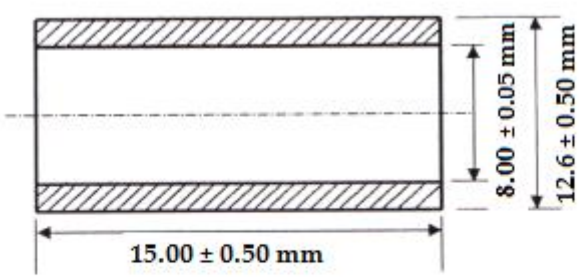


Figure 5.1 Work Piece

5.1.12 Initial Surface Roughness of Work-piece

For each set of experiments, a large number of test specimens, many more than the requirements were prepared. This surface roughness (Ra) and the cavity internal diameter (ID) were measured and the required number of those specimens whose initial surface roughness of hole was in quite narrow range was chosen from the lot so as to avoid any extraneous effect in response parameters. The range of initial surface roughness of work-piece was selected from 3.5-5.8 microns.

The selected parameters and their range for the detailed experiments are shown in Table 5.1.

Table 5.1 Selected Process Parameters and their Range

S.No.	Process Parameter	Range	Unit
1	Type of material (Brass, gun-metal, mild steel)	—	—
2	Extrusion Pressure	2-6	N/mm^2
3	Number of cycles	3-7	No.
4	Abrasive particle size	6-8	Micron
5	Media Flow Volume	290	Cm^3
6	Abrasive to media concentration	1.1 to 1:1	% by weight
7	Polymer-to-Gel Ratio	1:1	% by weight
8	Temperature of media	32 ±2	°C
9	Reduction Ratio	0.95	—
10	Initial Surface Roughness	3.5-5.8	µm

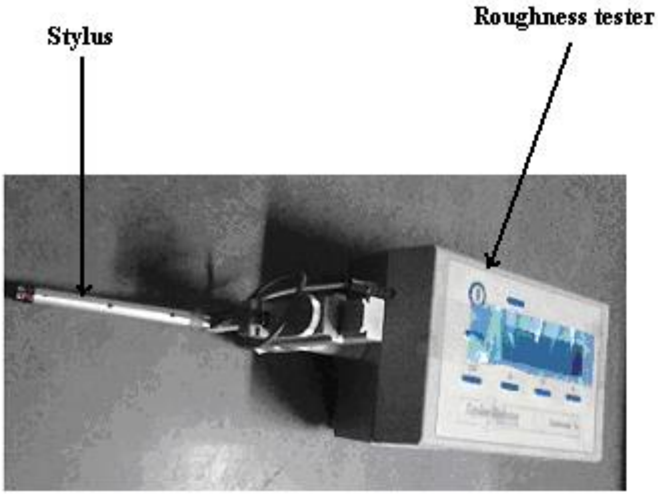
5.2 RESPONSE CHARACTERISTICS

The effect of selected process parameters was studied on the following response characteristics of Helical AFM process:

- Percentage improvement in surface roughness (R_a)
- Material Removal (MR)

5.2.1 Percentage Improvement in Surface Roughness (ΔRa)

The surface roughness (R_a) was measured at several random locations on the internal cylindrical surface using a taylor hobson Surface Roughness Tester.



Taylor Hobson Surface Roughness Tester

The average of R_a is calculated and the percentage improvement in roughness was estimated as:

$$\Delta\, R_a = \frac{(initial\ Roughtness - Roughness\ after\ machining)x\ 100}{initial\ Roughness}$$

This characteristic was chosen for the reason that machining by drilling, turning, boring etc. Almost always has an unavoidable variability in surface roughness value, which may affect the final roughness value.

5.2.2 Material Removal

Material removal rate was not taken as a response parameter in Helical AFM process because the amount of material removal changes from time to time and it is a function of surface roughness or surface conditions. The material removal signifies the amount of material that has been removed from a specimen in a specified number of process cycles. It was estimated by citing the difference between initial weight of the specimen and final weight of the specimen after processing at a specified set of conditions by Helical AFM. A precision electronic balance CAY 220 of least count 0.1 mg was used to measure the weight of the specimens.

5.3 SCHEME OF EXPERIMENTS

The experiments were designed to study the effect of some of the Helical AFM parameters on Response characteristics of Helical AFM process. The design was accorded to an L9 orthogonal array based on Taguchi method to study the effect of helix rod and other main AFM process parameter. The main parameters of type of material (M), Number of cycle (N), Extrusion pressure (P), have been selected at three levels considering no-interaction among them. The non-linear behavior, if exist among the process parameters can be studied if more than two levels of the process parameters are used. The quality characteristics under the consideration are material removal and percentage improvement in surface roughness (ΔRa). The selected no of process parameter and their levels are given in table no 5.2

Table 5.2 Process parameters and their values at different levels

Symbol	Process Parameters	Unit	Level 1	Level 2	Level 3
H	Type of material		Mild steel	Brass	Gun metal
P	Pressure	N/mm^2	2	4	6
N	Number of cycle	N	3	5	7
Po 200, Media Flow Volume: 290 cm^3, Reduction Ration: 0.95, Temperature: 32 + 2°C, Extrusion Pressure (P): 6N/mm^2, Flow Rate (F): medium and constant Approximate Pressure difference: 15N/mm^2), Initial Surface Roughness of Work-piece:3.5-5.8 micron, Media Viscosity: 810 Pas					

The scheme of experiments based on tagauchi's L9 orthogonal Array (OA) for setting of various parameters is as given in the table5.3

Table 5.3 L_9 (3^3)OA (Parameters Assigned) with Response

Exp no.	Run Order	Parameters Trial Conditions			Response(Raw Data)			S/N ratio(db)
		H	P	N	R1	R2	R3	

1	**5**	**1**	**1**	**1**	X_{11}	X_{12}	X_{13}	**S/N(1)**
2	**2**	**1**	**2**	**2**	X_{21}	X_{22}	X_{23}	**S/N(2)**
3	**6**	**1**	**3**	**3**	X_{31}	X_{32}	X_{33}	**S/N(3)**
4	**3**	**2**	**1**	**2**	X_{41}	X_{42}	X_{43}	**S/N(4)**
5	**8**	**2**	**2**	**3**	X_{51}	X_{52}	X_{53}	**S/N(5)**
6	**9**	**2**	**3**	**1**	X_{61}	X_{62}	X_{63}	**S/N(6)**
7	**7**	**3**	**1**	**3**	X_{71}	X_{72}	X_{73}	**S/N(7)**
8	**4**	**3**	**2**	**1**	X_{81}	X_{82}	X_{83}	**S/N(8)**
9	**1**	**3**	**3**	**2**	X_{91}	X_{92}	X_{93}	**S/N(9)**
Total					**Σ**	**Σ**	**Σ**	
R1, R2 and R3shows response value for three repetitions of each experiment 1, 2 and 3 represents levels of parameters X_{IJ} represents different measured values of quality characters.								

5.3.1.1 PRECAUTIONS TAKEN DURING EXPERIMENTATION

While performing various experiments, the following precautionary measures were taken:

1. Each experiment is repeated three times to avoided experimental error.
2. The experiments repeated randomly in order to avoid bias, if any, in the results.
3. As the experiments proceeds the cutting edges of abrasive particles wear off and become dull which result in less favorable results are produced in later experiments secondly the particles of work piece material mixed with the media and as the time proceeds the volume of work piece material inside the media increases which deteriorate the finishing action. To avoid this large volume of the media is prepared and after each experiment the used media is taken out from the cylinder and throughout mixed with the fresh media contained in large container. The media for

next trial is taken from this mix. For the limited number of experiments conducted, this would ensure with reasonable reliability that the media used for each of the experiment run contain approximately equal amount of fresh grains(grain with sharp edges)

4. Each set of experiments was performed at room temperature in a narrow range (32 ± 2 °C).

5. Before any measurement was taken, the work-piece was cleaned with acetone.

6. The surface roughness was measured in the direction of flow of media and at several random points all over the cavity of the work-piece.

5.3.2.2 EXPERIMENTATION

The three process parameters viz. type of material, Extrusion Pressure and Number of Cycles are selected as given in Table 5.7. The parameters which were kept constant are also given in the Table 5.6. The process parameters were varied according to the values as shown in Table 6.3. Experiments were conducted according to the test conditions specified by the L_9OA (Table 6.4). Each experiment was repeated three times in each of the trial conditions. Thus, 27 work-pieces were selected having initial surface in close range of (6.2-7.4). In each of the trial conditions and for every replication, the percentage improvement in surface roughness and material removal were measured.

The data is recorded in Table 5.4.

Table 5.4 Experiment Result of Various Response Characteristics

Exp No.	Run Order	%Improvement in Ra			S/N Ratio(db)	Material Removal(mg) MR			S/N Ratio(db)
		R1	**R2**	**R3**		**R1**	**R2**	**R3**	
1	5	8.05	7.50	7.09	17.55	1.8	1.5	1.6	4.26
2	2	14.35	16.20	23.79	25.15	3.0	4.3	2.5	10.28
3	6	10.86	9.70	7.10	19.29	8.7	4.9	7.8	17.06
4	3	15.50	8.24	14.80	22.17	7.6	3.8	7.7	16.07
5	8	21.85	9.63	10.10	22.83	8.1	7.9	7.6	17.91
6	9	9.83	6.20	14.20	20.06	6.3	7.5	7.4	16.98
7	7	9.04	7.30	9.20	18.60	4.8	7.7	4.8	15.21
8	4	8.42	14.84	23.90	23.92	5.0	3.2	4.7	12.66
9	1	13.16	18.65	18.52	24.49	8.9	5.9	8.9	17.95
Total		111.06	98.26	128.70		54.2	46.7	53	
		$T_{\Delta Ra}$ = Overall mean of ΔRa =12.51%				T_{MR} = Overall mean of MR =5.70mg			

CHAPTER 6

DISCUSSION OF RESULT

6.1 ANALYSIS AND DISCUSSION OF RESULT

Tagauchi's method was used to plane the experiments. The response characteristic data already have been provided in chapter 5(Table). Tagauchi have shown a standard procedure to analyze the data. The same method has been used here. The average values and S/N ratio of quality/response characteristics for each parameter at different levels are calculated from experimental data. The main effect of process parameter both for raw data and S/N data are plotted. The response curves (main effect) are used for examining the parametric effect of response characteristics. The most favorable condition (optimal setting) of process parameters in term of mean response characteristics by analyzing response curves and the ANOVA tables.

The results of experiments provide insight into the surface wear behavior of selected brass,gun metal, mild steel materials when it is processes by AFM. The effect independent AFM process parameters type of materials, Number of cycle, Extrusion pressure (while keeping other parameter constant) on selected response characteristics (material removal and percentage improvement in surface roughness) have been discussed further. The average values of response characteristics and S/N ratio (in db) for each parameter at the selected three different levels (L_1, L2, and L3) are calculated from table 5.4.

6.1.1. Effect on material removal

The average value of material removal (MR) and S/N ratio for each parameter at levels L_1, L_2, L_3 are calculated and given in table 6.1

Table 6.1 Average Values and Main Effect: Material Removal, MR (in mg)

Process parameter	**Level**	**Type of material(M)**		**Extrusion pressure(P)**		**Number of Cycle(N)**	
Type of data		**Raw Data(mg)**	**S/N Ratio**	**Raw Data(mg)**	**S/N Ratio**	**Raw Data(mg)**	**S/N Ratio**
Average value	L1	4.01	10.02	4.58	11.14	4.33	11.07
	L2	7.1	16.47	5.14	13.23	5.84	13.90
	L3	5.98	14.73	7.36	16.86	6.92	16.25
Main Effect	L2-L1	3.08	6.45	0.555	2.09	1.51	2.82
	L3-L2	-1.11	-1.74	2.22	3.62	1.07	2.34
DIFFERENCE $((L_3-L_2)-(L_2-L_1))$		-4.2	-8.19	1.66	1.53	-0.433	-0.48
L_1, $L_2$and L_3 represent levels 1, 2 and 3 respectively of parameters. L_2-L_1 is the average main effect when the corresponding parameter changes from level1 to level 2. L_3-L_2 is the main effect when the corresponding parameter changes from level 2 to level 3.							

The main effects of different process parameter on the material removal (MR) are plotted as figures 6.1(a, b.c,)

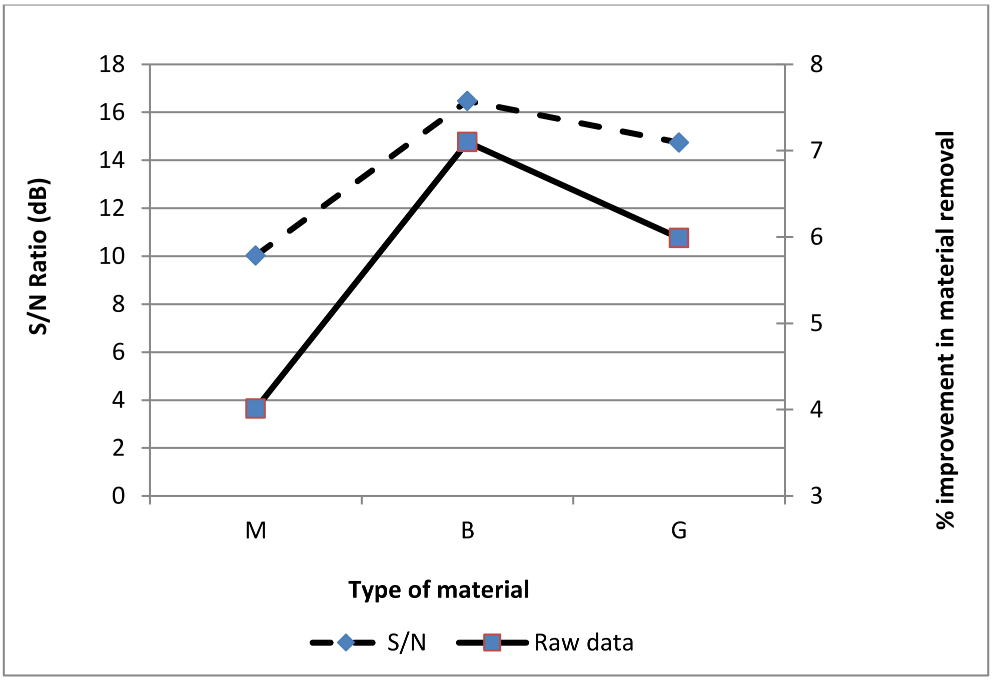


Figure 6.1(a) Effect of type of material (MR and S/N Ratio)

Fig 6.1 shows that % improvement in material removal is at second level (B) brass as a workpiece material is attributed to the fact that brass is more soft in nature compare to the other two material i.e. gun metal and mild steel as a work piece material and give more material removal comparatively with other two material . Lowest material removal rate is at first level (M) in mild steel as a work piece material is due to the fact that it is more harder than other two material resulting in less removal of material when 3 start helical drill bit is used.and similarly gun metal as a workpiece give more metal removal compare to mild steel and less letal removal than brass as a work piece material and lies between two material.But overall effect of 3 start Helix type of drill bit on material removal is insignificant as observed in both the ANOVA tables(Table nos 6.2 and 6.3) for raw data and S/N Ratio data.

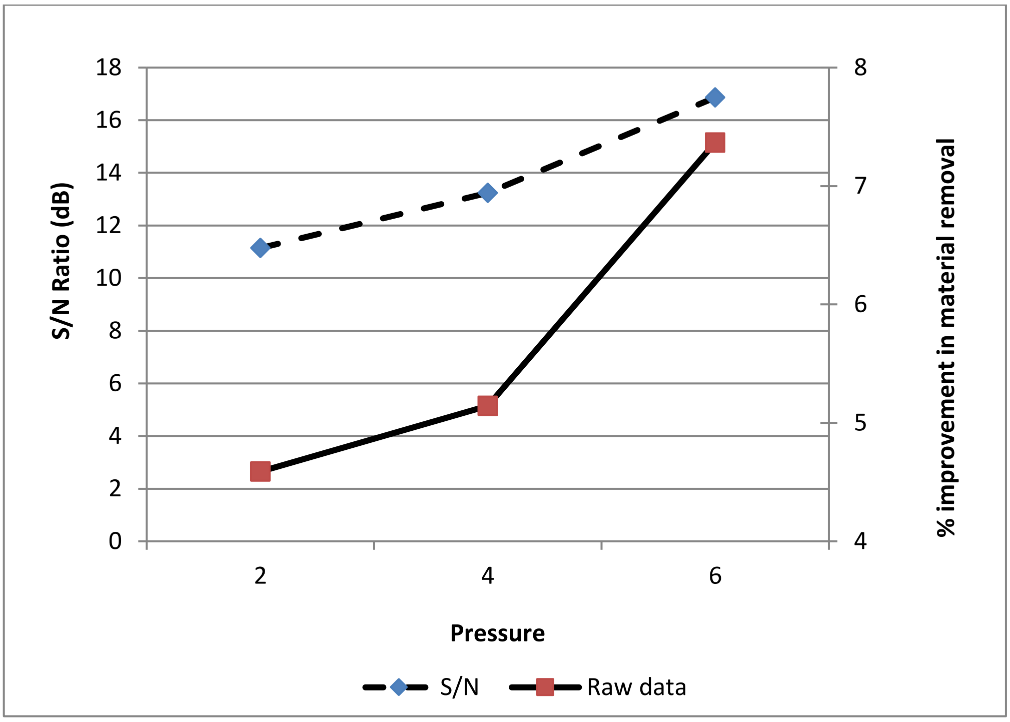
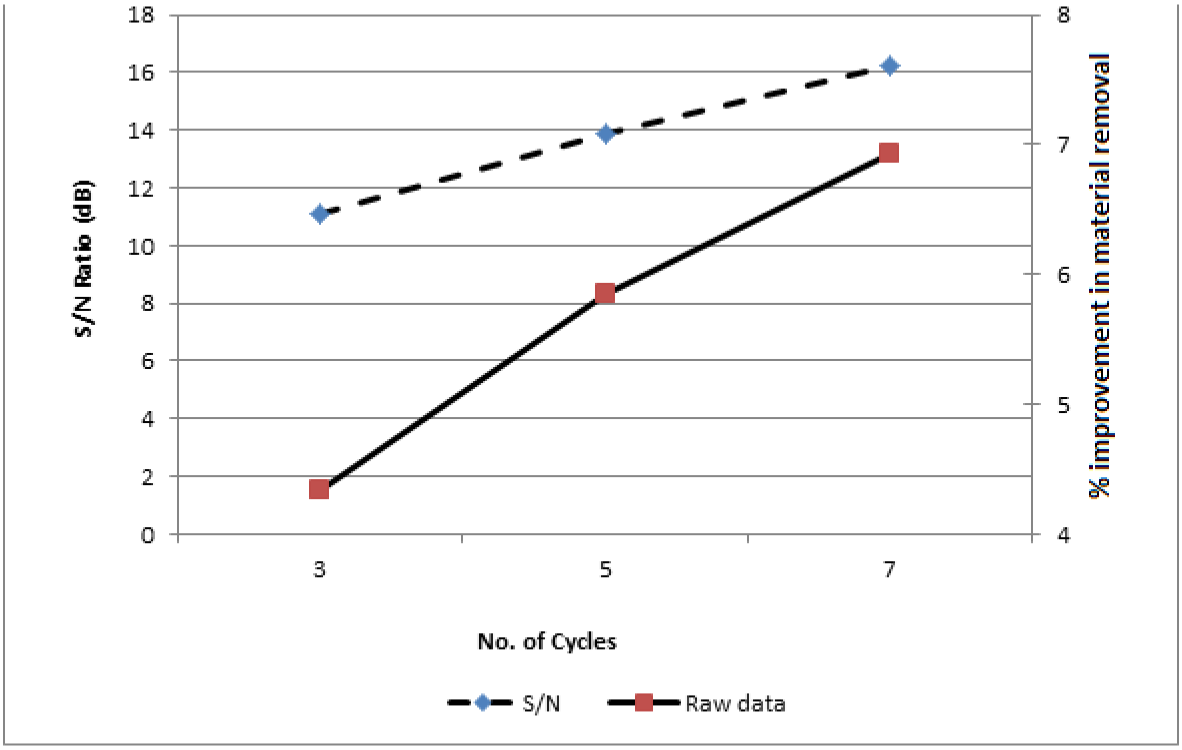


Figure 6.1(b) Effect of Extrusion Pressure on (MR and S/N Ratio)

Figure 6.1(b) show that with the increase of extrusion pressure material removal increase which is maximum at third level i.e. at 6 MPa and minimum at first level i.e. at 2 MPa.. Material removal increases with the presence of stationary helical drill-bit due to a combination of forces (axial, radial, and centrifugal forces), three types of flows (axial, reciprocating and scooping flow) that occur in finishing zone and remixing of medium at exit from the finishing zone resulting in more active grains improvement in material removal respectively. Due to the combination of different flows, the work-piece to abrasive contact length is no longer a straight line, rather it becomes curved; hence, the number of peaks that can be sheared increases, leading to higher material removel . At the third level of increased pressure (6MPa) the cutting force is quite large to remove more material which results in increase in combination of forces (axial, radial, and centrifugal forces), tends to more metarial removal than intial stage. The effect of extrusion pressure is significant in ANOVA table based on Raw Data and S/N ratio (Table 6.2)



% improvement in material removal

Figure 6.1(c) Effect of No of Cycle on (MR and S/N Ratio)

The figure 6.1(c) shows that as the no of cycle increase from 3 to 7 the material removal increases. More no of cycle means more abrasion action and more material removal. The material removal rate initialy is low but as the no of cycle increases material removal rate increases. The reason is as the no of cycle increases some of the abrasive particles become dull so along with cutting action rubbing action takes place which result in more material removal rate. However rubbing action deteriorate the surface finish. The effect of No of Cycle is significant in ANOVA table based on Raw Data and S/N ratio (Table 6.3).

6.1.2 Selection of optimum levels

Table 6.2 Pooled ANOVA (Raw Data MR)

Table 6.3 Pooled ANOVA (S/N Ratio Data, MR)

Source	**SS**	**DOF**	**V**	**F-RATIO**	**P%**
Type of Material	44.06	2	22.03	12.37*	29.57
Extrusion Pressure	38.88	2	19.44	10.92*	26.09
No of cycle	30.44	2	15.22	8.54*	20.43
Error	35.60	20	1.78		23.89
TOTAL(T)		26			100
All parameter are significant at 95% confidence level, $F_{critical}$= 3.49 SS-Some of square, DOF-Degree of freedom-variance					

SOURCE	**SS**	**DOF**	**V**	**F-RATIO**	**P%**
Type of Material	66.84	2	33.42	33.27*	41.93
Extrusion Pressure	50.27	2	25.13	25.02*	31.53
No of cycle	40.28	2	20.14	20.04*	25.26
Error	2.00	2	1.00		1.26
Total (T)	159.41	8			100
All parameter are significant at 95% confidence level, $F_{criticl}$=19 SS=Some of square, DOF-Degree of Freedom, V-Variance					

6.1.3 Effect on %age improvement in surface roughness

The average value of %age improvement in surface roughness and S/N ratio for each parameter at level L_1, L_2, $L_3$are calculated and given in table 6.4.

Table 6.4 Average values and Main effect; %age improvement in R_a (ΔR_a)

Process parameter	**Level**	**Type of material (H)**		**Extrusion pressure**		**Number Of Cycle(N)**	
Type of data		**Raw Data (% R_a)**	**S/N Ratio**	**Raw Data (% R_a)**	**S/N Ratio**	**Raw Data (% R_a)**	**S/N Ratio**
Average value	L1	11.62	20.32	9.74	19.16	13.00	21.31
	L2	12.37	20.81	17.23	23.96	18.13	24.35
	L3	17.55	24.16	14.58	22.17	10.42	19.63
Main Effect	L2-L1	0.745	0.490	7.48	4.80	5.13	3.03
	L3-L2	5.18	3.34	-2.65	-1.7	-7.71	-4.71
DIFFERENCE ((L_3-L_2)-(L_2-L_1))		4.44	2.85	-10.13	-6.5	-12.84	-7.75

L_1, L_2 and L_3 represent levels 1, 2 and 3 respectively of parameters. L_2-L_1 is the average main effect when the corresponding parameter changes from level 1 to level 2. L_3-L_2 is the main effect when the corresponding parameter changes from level 2 to level 3.

The main effects of various parameters at the selected levels on the %age improvement in surface roughness are plotted in the Fig 6.2(a, b, c).

Fig 6.2(a) Effect Of Type Of Drill Bit on %age improvement in R_a

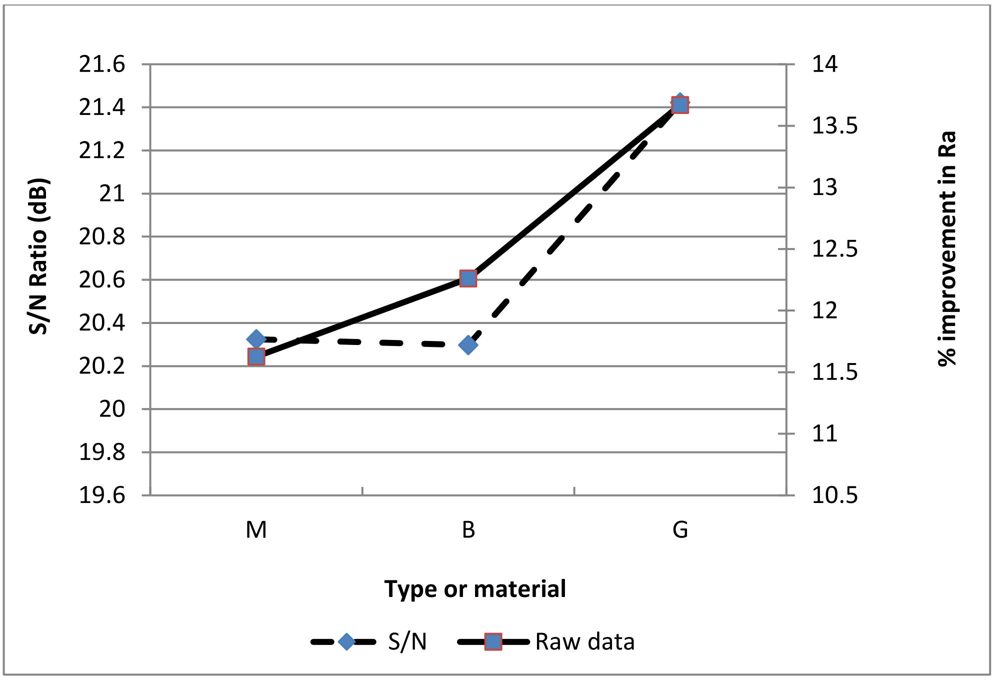


Fig 6.2(a) Effect of Type of Material on %age improvement in R_a

Fig 6.2 (a) shows that maximum ΔR_a and S/N Ratio is at the third level (G) at Gun metal as a work piece with three start helical profile drill bit. The lowest ΔRa and S/N ratio has been observed at first level (M) in case of mild steel as a work piece material with 3 start helical profile drill bit . For ΔRa and S/N ratio brass lies between mild steel and gun Metal as shown in graph .The overall effect of type of material on the %age improvement in ΔRa is insignificant based on S/N Ratio data (ANOVA Table no. 6.5), and it is also insignificant based on raw data (Table no 6.6).

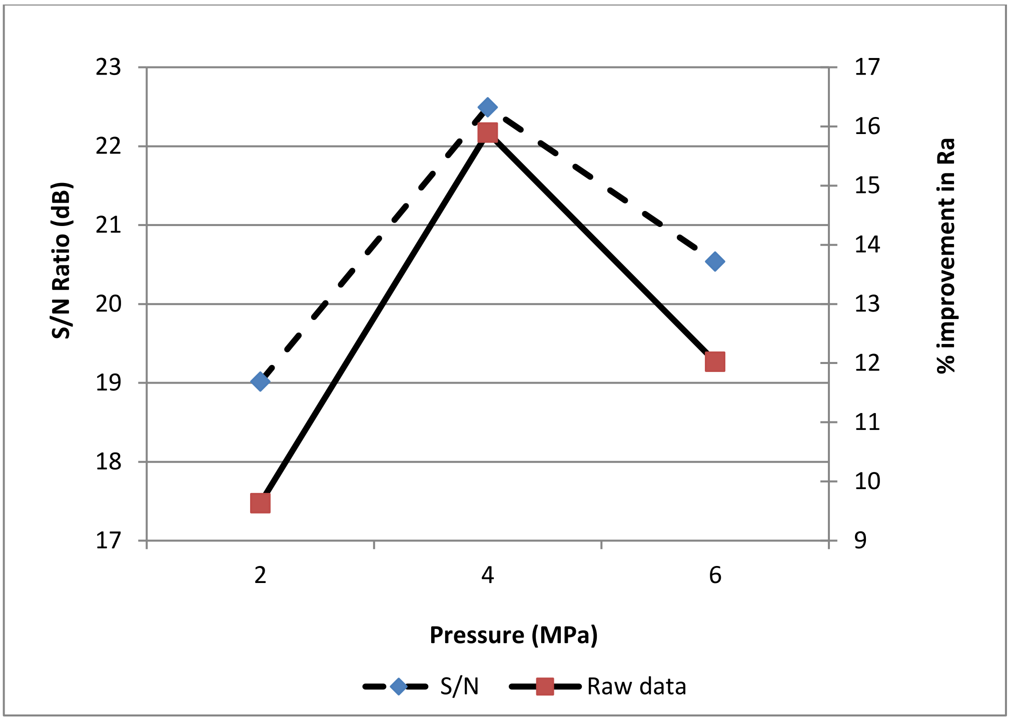


Figure 6.2 (b) Effect of Pressure on(ΔRa and S/N Ratio)

Fig 6.2(b) shows that %age improvement in Ra and S/N ratio increases as the pressure increases up to 4 MPa than it decreases with further increase in pressure up to 6 MPa. The increase up to 4 MPa can be attributed to the fact that as the pressure increases the force involved in cutting action increases and resulting in more no of peaks are sheared off which result in smother surface. At this pressure we got very smooth surface further increase in pressure enable the abrasive particles to strike the Surface with greater force and resulting in deeper scratches, and poor surface finish. Although the effect of extrusion pressure is significant in the ANOVA Table based on Raw Data (Table 6.5), and insignificant based on S/N ratio.

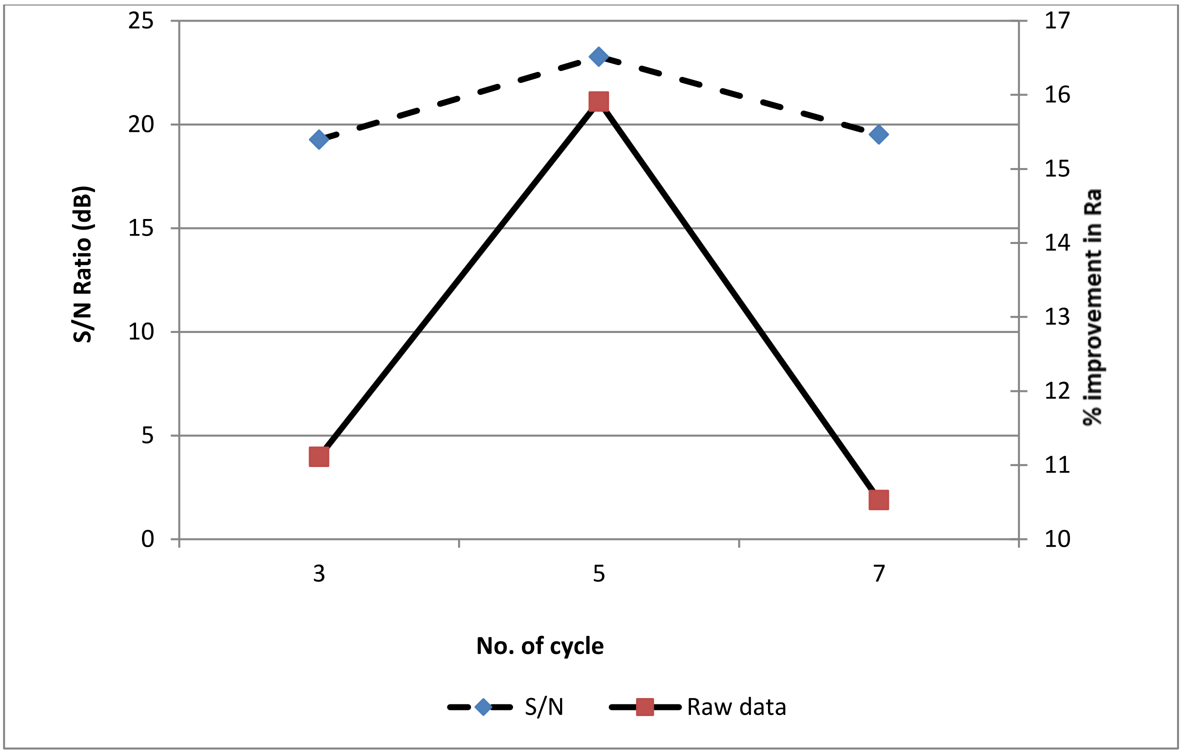


Fig 6.2(c) Effect of Number of Cycle on (ΔRa and S/N Ratio)

Fig 6.2(c) shows that initialy as the number of cycle increases %improvement in Ra and S/N ratio increases and is max at 5 no of cycle with further increase in no of cycle increases %improvement in Ra and S/N ratio decreases. As no of cycle increses we get better and better surface finish and a very good surface finish at 5 no of cycle. Further movement of abrasive particles on the surface beyond 5 no of cycle erode the surface and we get detirerated surface finish. Overall the effect of no of cycle on %improvement in Ra is significant in both S/N ratio and raw data table.

6.1.4. Selection of optimal levelsTable

6.5 Pooled ANOVA(Raw Data,%age imp inΔRa)

SOURCE	SS	DOF	V	F-RATIO	P%
Type of material	19.68	2	9.84	0.543	2.74
Pressure	179.77	2	89.88	4.96*	25.02
Number of cycle	156.94	2	78.47	4.33*	21.84
ERROR	361.96	20	18.09		50.38
TOTAL	718.37	26			100
*significant at 95% confidence level, $F_{criticle}$=3.49 SS-Sum of Square, DOF-Degree of Freedom, V-Variance					

Table 6.6 Pooled ANOVA (S/N Ratio Data, %age imp in ΔR_a)

SOURCE	**SS**	**DOF**	**V**	**F-RATIO**	**P%**
Type of material	2.47	2	1.23	7.20	4.83
Pressure	18.23	2	9.11	53.03*	35.63
Number of cycle	30.11	2	15.05	87.60*	58.85
ERROR	0.343	2	0.1719		2.68
TOTAL	51.17	8			100
*Significant at 95% confidence level, $F_{critical}$= 19 , SS-Sum of squares, DOF-Degree of freedom, V-variance					

6.2 Estimation of optimum response characteristics

In this section, the optimum values of the response characteristics along with their respective confidence intervals have been predicted. The results of confirmation experiments have also been presented to validate optimal result .The optimal level of the process parameters have been identified from the selected response characteristic s. The optimal value each response characteristic is predicted considering the effect of the significant parameters only. The average value of the response characteristic obtained through the confirmation experiments must lie with in the 95% confidence level, CE_{CE} (equation 4.5).However the average value of quality characteristic obtained from the confirmation experiments may or may not lie within 95% confidence interval, CL_{POP} (calculated for the mean of the population, equation 4.6), The Taguchi approach for the predicted means has been presents in section (Chapter 4)

As observed the optimum values for the maximum MR are $M_2P_3N_3$ with any level of N for raw data and N_3 with any levels of N for S/N data. For the confirmation experiments on the basis of raw data the optimal settings have been take as $M_2N_3P_3$.

For maximum percentage improvement in R_a are N_2P_2 for raw and M_3 with M,N,P set at any level for the S/N data . Based on raw data the optimum settings for the maximum percentage improvement in the surface roughness are $N_2P_{2.}$

Based on the optimal selection of the process the optimum response parameters of the material removal and Percentage improvement in surface roughness have been estimated with the confidence intervals as further.

6.2.1. Material Removal (MR)

The mean at the optimal MR (optimum values of the response characteristics) is estimated [40]as

$$MR = \bar{M}_2 + \bar{P}_3 + \bar{N}_3 - 2\bar{T}$$

T = overall mean of the response = 5.78 mg (Table 5.4)

Average value of MR at the second level of type of material

= 7.12mg (6.1)

Average value of MR at the third level of extrusion pressure

= 6.32 mg

Average value of MR at the third level of no.of cycle

= 6.83 mg

Substituting these values, MR = 8.71 mg

The confidence interval of confirmation experiments (CL_{CE}) and of population (CL_{POP}) is calculated by using the following equation [4.1]

$$CI_{CE} = \sqrt{F_a\,(1, f_e)V_e\,\left[\frac{1}{n_{eff}} + \frac{1}{R}\right]}$$

$$CI_{POP} = \sqrt{\frac{F_a\,(1, f_e)V_e}{n_{eff}}}$$

Where F_α (1, f_e) = The F- ratio at the confidence level of (1-α) against DOF 1 and error degree of freedom f_e = 4.35 (Tabulated F value)

f_e = error DOF = 20 (Table 6.2)

N = Total no of result =27 (treatment =9, repetition =3)

R = Sample size for confirmation experiments = 3

V_e = Error variance =1.78 (Table 6.5)

$$n_{eff} = \frac{N}{1+[DOF\ associated\ in\ the\ estimate\ of\ mean\ responce]}$$

= 3.85

So, CL_{CE} = ± 2.14

and CL_{POP} = ± 1.41

The 95% confirmation interval of predicted optimal range (for confirmation run of three experiment) is:

Mean MR – CI_{CE} <MR >MR + CI_{CE}

6.57< MR >10.85

The 95% confirmation interval of the predicted mean is :

Mean MR – CI_{POP} <MR >MR + CI_{POP}

7.3< MR >10.12

6.2.2 Percentage improvement in R_a

The mean of the percentage improvement in R_a optimum values of the response characteristics is estimated [G3] as :

$$\Delta R_a = \bar{N}_2 + \bar{P}_2 + \bar{T}$$

T = overall mean of the response = 12.51% (Table 5.4)

Average value of % age improvement in R_a at the second level of no of cycles

= 15.81%

Average value of % age improvement in R_a at the second level of extrusion pressure

= 15.86 %

Substituting these values, % improvement in ΔR_a = 19.16 %

The confidence interval of confirmation experiments (CL_{CE}) and of population (CL_{POP}) calculated by using the following equation [41]:

$$CI_{CE} = \sqrt{F_a\,(1, f_e)V_e\ \left[\frac{1}{n_{eff}} + \frac{1}{R}\right]}$$

$$CI_{POP} = \sqrt{\frac{F_a\,(1, f_e) V_e}{n_{eff}}}$$

Where F_α (1, f_e) = The F- ratio at the confidence level of (1-α) against DOF 1 and error degree of freedom fe = 4.35 (Tabulated F value)

fe =error DOF = 18 (Table 6.5)

N= Total no of result =27 (treatment =9, repetition =3)

R = Sample size for confirmation experiments = 3

Ve = Error variance =18.09 (Table 6.5)

$$n_{eff} = \frac{N}{1+[DOF\ associated\ in\ the\ estimate\ of\ mean\ responce]}$$

= 5.4

So, CL_{CE} = ±6.38

and CL_{POP} = ± 3.81

The 95% confirmation interval of predicted optimal range (for confirmation run of three experiment) is:

12.78< %age improvement in Δ$\mathbf{R_a}$ >25.54

The 95%age confirmation interval of predicted mean is

15.35<%age improvement in Δ$\mathbf{R_a}$ >22.97

Confirmation Experiments

In order to validate the results obtained, three confirmation experiments have been conducted for response characteristics of MR and %age improvement surface roughness .For the maximum MR, the optimal levels of the process parameter are $M_2N_3P_3$. whereas for the maximum %age improvement surface roughness the optimal parameters settings are N_2P_2

M_2 – Brass as a work-piece material at second level

N_3 – Third level of number of cycles (7 cycles)

P3 – Extrusion Pressure at the third level (6 MPa)

N_2 – Second level of number of cycles (5 cycles)

P2 – Extrusion Pressure at the second level (4 MPa)

The results are given in Table 6.7. The values of MR and %age improvement in Ra obtained through the confirmation experiments are within 95% of Cl_{CE} of respective response characteristic. It is to be pointed out that these optimal values are within the specified range of process parameters (Table 5.2). Any exploration should be confirmed through additional experiments.

Table 6.7 Predicted Optimal Values, Confidence Intervals and Results of Confirmation Experiments

Response Characteristic	Optimal Process Parameters	Predicted Optimal Value	Confidence Intervals 95%	Actual Value(Avg of Confirmation Exp)
MR	$M_2N_3P_3$.	8.71 mg	CI_{CE} : 6.57< MR >10.85 CI_{POP}: 7.3< MR >10.12	8.94 mg
%Improvement in	N_2P_2	19.16%	CI_{CE}: 12.78<%Δ$\mathbf{R_a}$>25.54 CI_{POP} :15.35<%Δ$\mathbf{R_a}$>22.97	21.27%
CI_{CE} – Confidence interval for the mean of the confirmation experiments CI_{POP} – Confidence interval for the mean of the population				

CHAPTER 7

CONCLUSION AND SCOPE FOR FUTURE WORK

7.1 CONCLUSIONS

- In the experimental investigation on Helical AFM setup, a developed three start helical profile have been studied with three parameters viz type of material, extrusion pressure and no of cycle. It has been found that the use of new developed profile led to an improvement in the response parameter of percentage improvement in surface finish and material removal.
- For the design of experiment, the taguchi method approach has been employed. L_9 OA has been used for the plan of experiments.
- The two process parameters viz extrusion pressure, number of cycle have significant effect on the response parameter MR and % improvement in Ra whereas type of material has significant effect on the response parameter MR but insignificant on the response parameter of % improvement in Ra .
- The result shows that type of material have 29.57%, number of cycle have 26.09 % and extrusion pressure have 20.43% contribution for response parameter of MR
- Type of material is a dominating process parameter with contribution of 29.57 %.
- The process parameter Extrusion pressure and number of cycle is significant for response parameter %age improvement in R_a. whereas the process parameter type of material is insignificant.
- It has been found that Extrusion pressure has 25.02% contribution and number of cycle has 21.84% contribution for response parameter %age improvement in R_a.
- Extrusion pressure is dominating process parameter with contribution of 25.02% for response parameter %age improvement in R_a.
- Extrusion pressure has a contribution of 20.43% and 25.02% towards the MR and %age improvement in R_a respectively within the selected range of 2MPa to 6MPa as the pressure increases MR increases. But we get better surface finish at the middle value i.e. at 4 MPa. After this as the pressure increases the %age improvement in R_a decreases.
- Number of cycle has contribution of 26.09 % and 21.84% towards the MR and %age improvement in R_a respectively within the selected range of 3 to 7 no. of cycle. As the number of

cycle increases MR increases. But number of cycle will least effectve at selected ranges in case of %age improvement in R_a.it gives maximum surface finish at middle value i.e. at 5 no. of cycle. Further increasing of number of cycle 5 to 7 no of cycle %age improvement in R_a decreases .

- The maximum % improvement in R_a has been observed in case of gun metal work piece and minimum % improvement in R_a in case of mild steel work piece while % improvement in R_a for brass work-piece is more than mild steel and less than gun metal work piece.
- A maximum improvement of 51.42% has been observed in the Surface finish. With the initial roughness 3.5 microns, an improvement to 1.70 microns has been observed on the inner cylindrical surface of the gunmetal work pieces.

7.2 SCOPE OF FUTURE WORK

- Different types and size of Helical profiles can be used for other ductile materials workpiece.
- FEM modeling and analysis for the Helical-AFM with different material and parameters can be analyzed .

CHAPTER 8

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